

EFFECT OF PRIMARY, SECONDARY AND MICRO NUTRIENTS ON MAIZE YIELD IN THE WENCHI MUNICIPALITY

ABSTRACT

One of the major constraints related to maize productivity is low soil fertility related mainly to continuous cropping without replenishment of depleted nutrients. In view of this, this study sought to assess the effect of different combinations of primary and secondary nutrients on the yield of maize in the Wenchi Municipality in the Brong-Ahafo Region. Five (5) treatments- Control (T1), NPK (T2), NPK + S + Mg + Ca+ B + Cu + Mo+ Zn (T3), Manure (T4) and T3 + Manure (T5)- were tested in a field experiment in a randomized complete block design (RCBD) with four replicates. The test crop was Lake 601 maize variety. Data for the research was collected on; total number of plants, stalk weight, hurst weight, cob weight, grain weight Nutrient Use Efficiency and Economic Viability. The data was analyzed with analysis of variance (ANOVA) on all measured parameters and the results were presented in graphs. From the results gathered, it was realized that the application of NPK + Sec_MN had a more positive impact on dry shoot weight and grain weight. The results obtained from the field experiment also indicated that it was more efficient to combine both NPK and secondary nutrients in maize production compared to applying the other treatments assessed in the study; such that, the combined effect gave more yield and subsequently generated more money (income). Based on the results obtained in the research, it was recommended that; much attention should be given to T3 (NPK + Sec_MN). Possibly, different doses of this treatment should be further tested to know the actual extent at which the secondary nutrients and the NPK can be combined to give the maximum yield. Similar research should also be staged at a different location to know whether similar results would be obtained.

INTRODUCTION

1.1 Background of the study

Maize (*Zea mays* L.) is the most cultivated cereal worldwide and its economic importance is manifested by the different ways of consumption, ranging from human food, animal feed to the high technology industry (Edwards 2009; Onasanya *et al.*, 2009). It is referred to as the cereal of the future for its valuable nutritional facts in human diet (Enyisi *et al.*, 2014). Maize is grown extensively in the temperate, sub-tropical and tropical regions of the world. World total maize production is 1.04 billion tonnes from which USA is the highest (50.4 %) producer producing 361 million tonnes, followed by China and Brazil (FAO, 2014). Africa produces 77.6 million tonnes of which 10.8 m tonnes is from Nigeria, harvested from 5.9 million ha land area (FAO, 2014). Despite its importance, maize yield is still considered low due to biotic, abiotic and agronomic factors (Onasanya *et al.*, 2009; Olaniyan, 2015). Parts of the major abiotic causes of the low yield in Africa are declining soil fertility and insufficient use of fertilizers, resulting in severe soil nutrient depletion (Buresh *et al.*, 1997). Continuous cultivation of crops on the same soil has resulted in increased rate of rapid loss of soil fertility (Uzoh *et al.*, 2015).

Poor soil fertility is recognized as the major constraint to food production and food security in Ghana. Most soils in Ghana are deficient in phosphorus (P) and nitrogen (N). Phosphorus, the second most widely limiting nutrient in soil after nitrogen (Balemi and Negisho 2012), is a critical macronutrient for plant growth; and in tropical agroecosystems soil, P deficiency is a major limitation to crop production (Mustonen *et al.*, 2012). In order to achieve optimum productivity of maize crop, balanced soil nutrients are required. This has necessitated the supplementing of soil natural fertility with fertilizers to replenish the soil for optimum yield.

The use of alternative fertilizer application strategies to achieve maximum yields and enhance nutrient use efficiency has been proposed for decades. Several studies had revealed the need for application of various nutrient elements such as nitrogen (N), phosphorus (P), potassium (K), sulphur (S), and some trace elements in order to boost crop productivity (Ayodele and Omotosho, 2008; Adekayode and Ogunkoya, 2010; Isitekhale *et al.*, 2013). Phosphorus (P) for instance is the second major nutrient essential for plant growth (Muhammad *et al.*, 2015) and one of the most limiting plant nutrients in crop production next to N, in most agricultural soils (Akande *et al.*, 2010). It plays an important role in many physiological processes that occur within a developing and maturing plant. It is involved in enzymatic reactions in plant, essential for cell division, important for seed and fruit formation, affects the quality of the grains and may increase the plant resistance to diseases (Onasanya *et al.*, 2009).

Nitrogen (N) is a vital plant nutrient and a major determining factor required for maize production (Shanti *et al.*, 1997). It is very essential for plant growth and makes up 1–4 % of dry matter of the plants. Nitrogen is a component of protein and nucleic acids and when N is suboptimal, growth is reduced (Haque *et al.*, 2001). Its availability in sufficient quantity throughout the growing season is essential for optimum maize growth. It also mediates the utilization of phosphorus, potassium, and other elements in plants (Brady, 1984). Optimal amount of these elements in the soil cannot be utilized efficiently if nitrogen is deficient in plants. Therefore, nitrogen deficiency or excess can result in maize yield reduction. Potassium is an essential nutrient and is also the most abundant

cation in plants. It plays essential roles in enzyme activation, protein synthesis, photosynthesis, osmoregulation, stomatal movement, energy transfer, phloem transport, cation-anion balance, and stress resistance. Maintaining adequate plant K is, therefore, critical for effective plant growth (Bashir, 2012).

Meanwhile, the essential micronutrients required by the plant cannot be overlooked. The role of micronutrients such as zinc involves from very simple to very complex reactions. Zn plays a very important role in plant metabolism by influencing the activities of hydrogenase and carbonic anhydrase and stabilization of ribosomal proteins (Tisdale, 1984). Zinc activates the plant enzymes by carbohydrate metabolism, maintaining the integrity of cellular membranes, protein synthesis and regulation of auxin synthesis (Marschner, 1995). Also, Zn is required for regulation and maintenance of the gene expression to induce tolerance of environmental stresses in plants (Cakmak, 2000). Also, nitrogen integrated with zinc improved plant height and yield in maize (Xia *et al.*, 2004). Sulphur is also becoming increasingly important as a yield limiting factor in many soils (Adetunji and Adepetu, 1989). It is recognized as the fourth major nutrient after N, P and K. It plays a key role in the synthesis of amino acids cysteine and methionine which are essential components of protein and useful in secondary metabolism. It has beneficial effects by lowering soil pH and improving physical condition of the soil (Choudhary and Das, 1996). Increasing level of S progressively enhanced the average total N uptake by maize and this increase in N uptake may be attributed to increase in N content of plant and dry matters yield due to increasing S levels (Jaliya *et al.*, 2012). Ray and Mughogho (2000) reported that S is a secondary nutrient taken up by most grain crops in amount namely 10 to 30 kg ha⁻¹. Synergistic effect of applied P and S was observed by Kumawat (2004). Antagonistic relationship between P and S was observed in mung and wheat (Islam *et al.*, 2006) and in maize (Muhammad *et al.*, 2015). This interaction influences the absorption of sulphur, in form of sulphate in the soil (Adetunji, 1991).

1.2 Problem statement and justification

Maize is the most widely cultivated crop and is of great importance to food security and livelihoods of most rural households (Tesfaye *et al.*, 2015). However, large yield gaps still exist. One of the major constraints to higher crop productivity among smallholder farmers is low soil fertility related mainly to continuous cropping without replenishment of depleted nutrients (Breman and Debrah, 2003; Sanchez, 2015). Estimates of current nutrient use vary between studies but all are low, with most countries applying less than 10 kg of nutrients per ha – sum of nitrogen (N), phosphorus (P) and potassium (K) inputs - in organic and chemical fertilizers (Rurinda *et al.*, 2013; Masso *et al.*, 2017). Increasing fertilizer input alone could close a large part of the yield gap (Mueller *et al.*, 2012), provided that good crop management practices such as weed and pest control are applied. A successful soil fertility program includes consideration of all macro and micronutrients critical for maize (*Zea mays* L.) growth and development. While maize macro nutrient requirements necessitate consideration on seasonal basis, micronutrient (Zn, Mn, Cu, Fe, B) deficiencies are less common due to smaller crop removal amounts and typically adequate soil supply in most maize producing regions where the soil pH is maintained between 6.0 and 7.0 (Rego *et al.*, 2007). However, maize grain sale prices have increased dramatically since 2000 to a record high of 16 kg⁻¹ on average during 2017, with prices reaching 18 kg⁻¹ during certain months. These record high maize prices have prompted many growers to use various products such as foliar micronutrient fertilizers to

potentially increase yield. In past research, maize yield response to micronutrient applications has varied as a result of environmental conditions such as soil mineralogy, organic matter, pH, moisture, temperature, and aeration. With the increase in maize yields due to important genetic improvements, demand for nutrients has also increased. Precise knowledge of nutrient uptake, partitioning and removal could help determine proper application timing and rates to combat inconsistency and increase the probability of a positive yield response. In view of this, this study seeks to determine the effect of different combinations of primary and secondary nutrients on the yield parameters of maize.

1.3 Research objectives

1.3.1 Main objective

The main objective of this is to increase maize yield in Wenchi through combined applications of primary and secondary nutrients.

1.3.2 Specific objectives

- i. To evaluate nutrient use efficiency (NUE) of maize under primary, secondary and micronutrient applications.
- ii. To evaluate grain yield of maize in response to applications of primary, secondary and micronutrients.
- iii. To assess the economic viability of maize under applications of the nutrients.

1.4 Research Questions

The research will attempt to find answers to the questions below:

- i. Does application of primary, secondary and micro nutrients improve nutrient use efficiency in maize?
- ii. Does application of primary, secondary and micronutrients improve grain yield of maize?
- iii. Does additional application of secondary and micro nutrients enhance economic viability in maize production?

LITERATURE REVIEW

2.1 Origin of maize

The origin of maize (*Zea mays* L) may be problematic to trace with certainty (Brown and Darah, 1985). However, it was believed that the important cereals are indigenous to the Western hemisphere, originating from Mexico. The genus *Zea* is from the family Graminae (Poaceae), commonly known as the grass family. Piperno and Flannery (2001) reported that Multitudes of maize subspecies were identified and classified based on the extent of starch components each of them have. It has short life cycle and requires warm weather. Maize generally is a tall, monoecious annual grass with overlapping sheaths, broad distichous blades and it is wind pollinated and both self and cross pollination are possible (Hitchcock and Chase, 1971). Maize is cultivated across the globe and provides a staple food for a greater proportion of the world's population. No important native toxins have been reported to be found in the genus *Zea* (IFBC, 1990).

2.2 Economic importance of maize

The annual production of maize is more than any other grain (ITTA, 2009). The increase in production could be attributed to its uses for food, feed and industry. Maize has been identified as the world's highest animal feed ingredient; It has high energy content, low fibre content and can easily be digested by most livestock species (Plessis, 2003). Maize is primarily used as feed grain in the United States contributing to more than 90 % of total feed produced and used (USDA, 2012). In sub-Saharan Africa, maize remains the number one staple food for an estimated 50 % of the population and provides 50 % of the basic calories. It is a vital source of carbohydrate, protein, iron, vitamin B, and minerals. Africans eat maize as a starch component in a variety of porridges, pastes, grits, and beer. Green maize (fresh on the cob) is eaten parched, roasted or boiled and baked and plays a crucial role in solving hunger problem after the dry season. All parts of the crop can be served as food and non-food products. Maize grains serve as a great nutritional value as they contain 10 % protein, 4.8 % oil, 8.5 % fibre, 72 % starch 1.7 % ash and 3.0 % sugar (Chaudhary, 1983).

Demand for maize for poultry feed in Ghana was expected to increase from 73,000 metric tons in 2010 to 118,100 metric tons by 2015 (MiDA, 2006). In developing world, it is consumed directly and also serves as staple food for some 200 million people especially in Latin America and Africa (ITTA, 2009). Fresh maize can be boiled or roasted and eaten or when dry the grains are milled in dry or wet states into floor or dough for various traditional meals. Braimoh and Vlek (2006) reported that maize contributes about 20 % of calories to the diet of communities in Ghana. The grains are rich in vitamins A, C and E (ITTA, 2009). It also contains proteins such as lysine and tryptophan (Onimisi *et al.*, 2009), minerals and fat (Buah *et al.*, 2009). In the industries, alcoholic beverages are produced from maize. Starch obtained from the grain is used in fabrics manufacturing and as adhesives (Buah *et al.*, 2009). It can also be processed as fuel (ethanol). The starch changes into sorbitol, dextrine, sorbic and lactic acid, and appears in household items such as beer, ice cream, syrup, shoe polish, glue, fireworks, ink, batteries, mustard, cosmetics, aspirin and paint (Plessis, 2003). The grain can be used as raw material for industries which can be processed into secondary products such as corn flacks and popcorn. Maize production, processing and sales both locally and as export commodity are major means of occupation and income generation for thousands of people worldwide (Bourdillon *et al.*, 2003).

2.3 Environmental requirements for maize crop production

2.3.1 Climatic factors

Successful cultivation of maize largely depends on the right choice of varieties so that the length of growing period of the crop matches the length of the growing season and the purpose for which the crop is being grown. The optimum temperature for maize growth and development is 18 to 32 °C and at tasselling 21 to 30 °C is ideal (Belfield and Brown, 2008). The critical temperature detrimental to yield is approximately 35 °C and above. Temperatures below 8 °C or above 40 °C usually cause cessation of development (Birch *et al.*, 2008). Temperatures that are outside the range of adaptation of a maize cultivar may impact negatively on factors such as photosynthesis, translocation, and pollen viability (Lafitte, 2000). Higher temperatures have a negative impact on kernel growth, kernel mass and protein accumulation (Monjardino *et al.*, 2006). Maize can grow and yield with as little as 300 mm of rainfall, which might result in 40 % to 60 % yield decline compared to optimal conditions; however, successful growth will be attained with a minimum annual rainfall of 600 mm. The preferred precipitation range for optimal growth is 500 to 1200 mm which should be well distributed throughout its growing stages (Belfield and Brown, 2008). Maize crop needs more than 50 % of its total water requirement after tasseling and inadequate soil moisture at grain filling stage results in a poor yield and shriveled grains. Prolonged cloudy period is harmful for the crop but an intermittent sunlight and cloud of rain is the most ideal for its growth. It needs bright sunny days for its accelerated photosynthetic activity and rapid growth (Akmal *et al.*, 2010).

2.3.2 Soil requirement

Maize plants grow well on most soils but less so on very heavy, dense clay and very sandy soils. The fertility demands for grain maize are relatively high. Up to about 200 kg N/ha, 50 to 80 kg P/ha and 60 to 100 kg K/ha are required by high yielding varieties (Bakht *et al.*, 2006). In general, the crop can be grown continuously as long as soil fertility is maintained (Plessis, 2003). Maize does well, in terms of growth and yield on soils with a pH range of 5.5 to 8 (Bakht *et al.*, 2006). The soil should preferably be well aerated and well drained as the crop is highly susceptible to water logging. Excess soil moisture causes major changes in physical and chemical properties in the rhizosphere; and under such condition, there is very little or no gaseous exchange between aboveground plant parts and inundated roots; therefore, plant roots suffer from extreme oxygen stress which inhibits growth and development (Zaidi *et al.*, 2003). The extent of damage due to excess moisture stress varies significantly with developmental stage, and past studies have shown that maize crop is comparatively more susceptible to excess moisture stress during the early seedling to tasseling stages (Zaidi *et al.*, 2003).

2.4 Growth parameters / stages of maize

Seedling emergence in maize usually occurs 6 to 10 days after planting (4-5 days under warm, moist soil conditions); if the seed is placed in a cool dry soil, it may take two weeks or longer for seedling emergence (Woltz *et al.*, 2006). From breaking through the soil surface to maturity, maize plant will undergo several growth stages. These stages are separated into two distinct categories: vegetative and reproductive stages. The vegetative stage ranges from the time the first fully open leaf is visible to tasseling. The reproductive phase is categorized into the following stages: silking stage (R1), kernel blister stage (R2), milk stage (R3), dough stage (R4), dent stage (R5) and physiological maturity stage

(R6). Silk emergence is technically the first recognized stage of the reproductive period. The silks serve the purpose of capturing pollen grains that fall from the tassel and moves them down the silk to the ovule where fertilization occurs (Nielsen, 2013). At kernel blister stage (R2), kernels are very small and white in color. The fluid that fills the kernels at this stage is usually clear in color. The kernels at this stage consist of about 85% water and will gradually decline from this point until harvest.

The milk stage occurs about 18 to 22 days after silking. The kernels at the stage contain mainly a white milky fluid. Dough stage occurs about 24 to 28 days after silking. At this stage, the kernel's milky inner fluid is becoming doughy as starch accumulation continues in the endosperm. At this time, the kernels have reached about 50 % of their mature dry weight (Nielsen, 2013). Dent stage occurs around 35 to 42 days after silking. The final stage is the physiological maturity stage at which the kernels have achieved peak dry matter accumulation. The hard starch layer has now reached the ear and a black abscission layer, called the black layer is now formed. This black layer signifies that the kernel is finished with its growth for the season. The kernel moisture content at this stage is around 30-35 %, depending on the hybrid and environmental conditions (Nielsen, 2013).

2.5 Determinants of maize grain yield

Grain yield of a maize crop is a function of the number of ovules that are developed, the potential final size of each ovule and the efficiency and duration of grain filling (Cazetta *et al.*, 1999). Out of these processes, kernel number and kernel size constitute kernel sink capacity, which is established early in kernel set and development (Cazetta *et al.*, 1999). Grain yield of maize crop is mainly determined by the final number of kernels per unit area that reach maturity. This number is strongly related to crop growth rate during a critical period of about 30 days centered around silking and to biomass partitioning to the ear during this period (Andrade *et al.*, 2002). Variations in grain yield in maize have been related mainly to variations in kernel number and kernel size; however, among the two, maize grain yield is mainly dependent on kernel number per unit area (Andrade *et al.*, 2002). Crop growth rate near flowering accounts for most of the variation in kernel number per plant (Andrade *et al.*, 2002). Kernel number is strongly affected by environmental conditions. Severe water and nutrient stress can greatly reduce potential kernel number per row. Conversely, excellent growing conditions can encourage unusually high potential kernel number (Ma and Subedi, 2005).

The position of leaves influences the rate and direction of translocation of photoassimilates (Ma and Subedi, 2005). Leaves above the ear, export principally to the ear during the post-silking period, while lower leaves export relatively less to the ear and more to the lower internodes and roots (Subedi and Ma, 2005). Kernel weight development during kernel filling period is usually described in terms of dry matter deposition through three phases which take place after flowering. During the first period of grain filling, called the lag phase, the number of starch deposition sites is established. Dry matter accumulation during this lag phase is almost zero, but water accumulation is rapid, driving endosperm expansion and increasing potential sink size. Kernels continue to accumulate water until about mid-grain fill, when kernel maximum water content is achieved (Borras and Westgate, 2006). In the second phase, termed effective filling period, kernel weight increases linearly. During the last phase, kernel growth rate decreases and kernels reach their final kernel weight (Borras and Westgate, 2006). Kernel

weight at physiological maturity depends on the potential kernel size established early in grain filling, and the plants' capacity to provide assimilates needed to fulfill this potential during grain filling (Borras and Westgate, 2006). Maize physiological traits that contribute to increased grain yield includes higher photosynthetic rate, leaf area duration, larger sink size, high leaf angle and decreased anthesis-silking interval (Borras and Westgate, 2006).

2.6 Effect of macro and micro nutrients on the growth and yield of maize

2.6.1 Macro nutrients

2.6.1.1 Nitrogen

Plants require N in the largest amount among the three major / primary nutrients (others being P and K). It has many functions including: promotion of rapid growth, increasing leaf sizes and quality, enhancing fruit and seed development; forms an integral component of many important components in plants including amino acids that are building blocks of proteins and enzymes, that are involved in catalyzing most biochemical processes (Brady and Weil, 2008). Thus, it plays a role in almost all metabolic processes. Nitrogen plays a pivotal role in several physiological processes in maize plants. Nitrogen is important for kernel initiation, contributes in determining maize sink capacity and helps to maintain functional kernels throughout grain filling. As determined by its functions N influences the rate of crop growth and crop quality. It increases the plumpness of the cereal grains, the protein content of both seeds and foliage, and the succulence of crops such as lettuce and radish (Foth and Ellis, 1988). Oversupplying of N especially with higher $\text{NH}_4^- \text{N} : \text{NO}_3^- \text{N}$ ratios, is reported to reduce calcium uptake (Bar-Tal *et al.*, 2001). On the other hand, calcium is needed for synthesis of strong cell walls (Capdevillea *et al.*, 2005). A quadratic relationship in Ca uptake with increase in N amount applied was reported from a study on N nutrition in pepper (*Piper nigrum* L.) in Israel in which a decrease of 50 % for Ca uptake was noted from the peak (at 7.0 mmol L⁻¹ N) to the highest application of 15 mmol L⁻¹ N (Bar-Tal *et al.*, 2001). Increasing available N or N application has also been reported to reduce oil content in some legumes such as soybean (*Glycine max* (L.) Merr.) and groundnuts (*Arachis hypogea*, L.) (Blumenthal *et al.*, 2008).

Nitrogen deficiency promotes a reduction in maize crop growth rate and subsequently reduces grain yield (Andrade *et al.*, 2002). Its deficiency in maize is often visually apparent through reductions in leaf area, leaf chlorophyll status, especially as leaves age and vegetative biomass. Such phenomenon decrease plant light interception, photoassimilate production, and final grain yield (Echarte *et al.*, 2008). Nitrogen deficiency in maize could also be indicated by yellowing of mature leaves starting at the leaf tips and then extending along the mid-ribs, stunted plants, delayed flowering and short, poorly filled ears (Hughes, 2006). Low nitrogen supply decreases grain yield by reducing grain number and individual grain weight (Hammad *et al.*, 2011). Availability of sufficient nitrogen to maize extends the periods of post-silking dry matter and N accumulation and this phenomenon has been associated with higher grain yields. However, increased N availability promotes greater yield responses with high yielding than with low yielding maize varieties (Ciampitti and Vyn, 2011).

Table 1: Reported quality characteristic improvement by nitrogen application in some crops

Crop	Quality characteristics	References
-------------	--------------------------------	-------------------

Wheat	Total protein content; gluten (protein that improves bread making quality)	Fuertes-Mendizábal <i>et al.</i> , 2012
Maize	Kernel weight, grain protein and seed starch	Campillo <i>et al.</i> , 2010; Kling <i>et al.</i> , 1998
Sweet potato	Crude protein	Phillips <i>et al.</i> , 2005
Potato	Protein content, starch and total carbohydrate content	Yassen <i>et al.</i> , 2011
Rice	Protein content	Sidkar <i>et al.</i> , 2008
Mandarin orange	Fruit size and weight	Hammami <i>et al.</i> , 2010

2.6.1.2 Phosphorus

Phosphorus is a very important macronutrient involved in most growth processes. It is an essential component of most organic compounds in the plant including nucleic acids, proteins, phospholipids, sugar phosphates, enzymes and energy-rich phosphate compounds, a common example being adenosine triphosphate (ATP) (Sylvia *et al.*, 2005; Brady and Weil, 2008). Research has determined that P improves crop quality in a number of ways including: reduced grain moisture content, winter hardiness, increased sugar content, increased protein content, increased P content, increasing proportion of marketable yields, better feed value, and improved drought and disease resistance in crops such as wheat and maize (Havlin *et al.*, 2005).

An 8 % increase in cowpea crude protein with 37.5kg P ha⁻¹ application compared with a control (without P application) was reported from a study done in Northern Guinea Savanna of Nigeria (Magani and Kuchinda, 2009). As noted under nitrogen discussion, most nutrients produce the best effects under balanced nutrition. A 25 % maximum protein content was reported from a plot fertilized at a combination of 50-75 kg NP ha⁻¹ as compared to other combinations of N (0, 25 and 50 kg ha⁻¹) and P (0, 50, 75 and 100 kg ha⁻¹) in Pakistan (Malik *et al.*, 2003). Synergistic effect is one of the factors that increases crop quality as far as N and P application are concerned. Application of 40 Kg P ha⁻¹ increased N and K accumulation in the maize grain by 22.5 % and 21.2 % respectively (Hussaini *et al.*, 2008).

2.6.1.3 Potassium

Potassium is an essential nutrient that is absorbed by plants in larger amounts than any other nutrient except N (Roy *et al.*, 2006). Unlike N, P and most other nutrients, K is not incorporated into structures of organic compounds; instead potassium remains in ionic form (K⁺) in solution in the cell and acts as an activator of many cellular enzymes (Havlin *et al.*, 2005). Therefore, it has many functions in plant nutrition and growth that influence both yield and quality of the crop. These include regulation of metabolic processes such as photosynthesis; activation of enzymes that metabolize carbohydrates for synthesis of amino acids and proteins; facilitation of cell division and growth by helping to move starches and sugars between plant parts. It is reported that among the many plant mineral nutrients potassium (K) stands out as a cation having the strongest influence on quality attributes that determine fruit marketability, consumer preference, and the concentration of critically important human-health associated phyto-nutrients or bioactive compounds (ascorbic acid and Beta carotene) (Jifon and Lester, 2009; Lester *et al.*, 2010). Some examples where fruit quality increased due to K application are

presented in Table 2. All the increase in quality as describe in this section can be attributed to the involvement of K in synthesis and movement of different products to their sinks (Havlin *et al.*, 2005). A condensed review on the effect of K on fruits and vegetable quality had been published (Lester *et al.*, 2010).

Table 2: Reported quality characteristics influenced by K application

Crop	Quality characteristics	References
Muskmelon	Ascorbic acid concentration; Beta carotene concentration; relative sweetness; consumer preference and marketability	Jifon and Lester, 2009; Lester <i>et al.</i> , 2010
Banana	Bunch weight; decreasing acidity; increasing shelf	Mitra, 2009
Tomato	Increased carotenoids and flavor	Mikkelsen, 2005
Pawpaw	Sugar content	Lester <i>et al.</i> , 2010

2.6.1.4 Sulphur

Sulphur is the most abundant element in the earth's crust (Havlin *et al.*, 2005). It is absorbed by plants as Sulphates (SO_4^{2-}). It is responsible for the formation of the disulphide bond between cysteine residues that help to stabilize the tertiary structure of proteins (Sylvia *et al.*, 2005). It is also needed in the synthesis of coenzyme A and chlorophyll. The deficiency of S leads to accumulation of non-protein N such as NO_3^- and amine (NH_2) (Havlin *et al.*, 2005). Sulphur deficiency has been reported to lead to accumulation of NO_3^- in vegetables which is dangerous as these lead to fatal conditions such as methemoglobinemia in infants and formation of cancer inducing nitrosamines (Sylvia *et al.*, 2005). Increased rice grain quality (N content) by S containing nitrogenous fertilizers, supernet (1.73 % N) and ammonium sulphate nitrate (1.66 % N) as compared to urea that produced 1.45 % N was reported in India (Chaturvedi, 2005). This could be attributed to the role of S in protein synthesis in which it is used as an essential component of amino acids and also the balanced fertilization that lead to the general high performance of the crop including synthesis of all N containing compounds such as proteins, chlorophyll and nucleic acids. An increase in glucosinolates, sulphur rich metabolites of the order Brassicales in the range of 25 % to more than 50 % with sulphur fertilization was also reported (Falk *et al.*, 2007). Sulphur application has been reported to increase the quality characteristic such as pungent smell in onions (Walker and Silva, 2008).

2.6.1.5 Calcium

Calcium is used in large amounts by plants second only to N and K (Brady and Weil, 2008). It is a major component of the middle lamella (Ca-pectates) of the cell wall. It strengthens the cell walls, is involved in cell elongation and division, membrane permeability, and activation of several critical enzymes (Brady and Weil, 2008). It is important in N metabolism and protein formation by enhancing NO_3^- uptake and it is also important in translocation of carbohydrates and other nutrients (Havlin *et al.*, 2005). In accordance with its functions, calcium influences crop and food quality. Calcium is less mobile such that its influence on crop quality is easily noted with foliar application. Seven-fold calcium foliar application also improved some fruit quality characteristics of 'Sinap or lovs kij' apple such as fruit calcium content (high quality) increased by 50 – 150

mg/kg and decreased bitter pit incidence (poor quality) by two times as compared with the control in Lithuania (Launaskas and Kvikliene, 2006).

2.6.1.6 Magnesium

Magnesium is another secondary nutrient element. It is important as a primary constituent of chlorophyll and as a structural component of ribosomes, it helps in their configuration for protein synthesis (Havlin *et al.*, 2005). It is also required for maximum activity of almost all phosphorylating enzymes in carbohydrate metabolism. Adequate levels of Mg in USA reported increased quality and profits of potato due to improved potato specific gravity (Hoyum, 2000). Increased specific gravity of potatoes can be attributed to increased carbohydrate synthesis and deposition from the leaves. Usually, the first things to be noticed due to influence of Mg are chlorophyll level, photosynthesis (photosynthetic CO₂ fixation), and protein synthesis, however, recently, distribution of carbohydrates among shoot and root organs have been reported as well (Cakmak and Yazici, 2010). These in turn affect quality of plant product depending on which part is used for food by humans or animals. A four-fold increase of sucrose in leaves of Mg-deficient sugar beets compared to the Mg-adequate sugar beet plants was reported and this affected quality of Mg-deficient sugar beets (Hermans *et al.*, 2004). This was attributed to inhibition of sucrose / sugar distribution from leaves to root organs in the Mg-deficient plants.

2.6.2 Micronutrients

Micronutrient elements such as Zn, Fe, Bo, Mo, Cu, Mn, Cl and Ni are known to be essential for plant growth. Others such as selenium (Se) and Co, which are needed in specific cases are commonly referred to as beneficial elements. For instance, Co is required by bacteria that fix nitrogen in legumes. Zinc (Zn) and iron (Fe) are some of the most important micronutrient essential for plant growth (Muthukumararaja and Sriramachandrasekharan *et al.*, 2012; Kumar *et al.*, 2012). Zinc is a major metal component and activator of several enzymes involved in metabolic activities and biochemical pathways (Kabata-Pendias and Pendias, 2011; Grotz and Guerinot, 2002). It is a functional, structural or regulatory co-factor of a large number of enzymes (Grotz and Guerinot, 2002). It is required in a large number of enzymes and plays an essential role in DNA transcription (Kumar *et al.*, 2012). Other functions of zinc include: catalyzing the process of oxidation in plant cell and is vital for the transformation of carbohydrates; and influencing the formation of chlorophyll and auxins, the growth promoting compounds (Mamatha, 2007). On the other hand, Fe in a constituent of enzyme system which brings about oxidation-reduction reactions in the plant, it regulates respiration, photosynthesis, reduction of nitrates and sulphates (Mamatha, 2007). These reactions are essential to plant development and reproduction. It should be noted that as the case with other plant micronutrients Zn and Fe limit plant growth when they are present both in low concentrations and in excessive concentrations due to deficiency and toxicity respectively (Conolly and Guerinot, 2002; Alloway, 2008).

Table 3: Crop quality characteristics improvements by some micronutrient's application in various crops

Crop	Quality characteristics	Nutrient element	References
Groundnut	Protein content; oil content	Zn	Nadaf <i>et al.</i> , 2013
Rice	Amino acid content; protein	Zn; Fe	Yuan <i>et al.</i> , 2012

	content; grain Zn and Fe content		
Pomegranate	Fruit weight; fruit diameter	Zn; Fe	Hasani <i>et al.</i> , 2012
Cotton	Ginning percentage; spinning constituency index (SCI)		Efe and Yapuzi, 2011
Chilli	Ascorbic acid concentration	Cu	Gangamrutha, 2008
Sweet pepper	Protein; total carbohydrate content; ascorbic acid content	Co	Gad and Hassan, 2013

2.7 Effect of organic manure on soil and yield

The application of animal manure to agricultural land has been viewed as an excellent way to recycle nutrients and organic matter that can support crop production and improve soil quality (Mugwe *et al.*, 2007). Manure application supplies organic matter which improves soil physical and chemical properties, thereby, increasing plant nutrient concentration and nutrient uptake (Mugwe *et al.*, 2007). Manure application also enhance soil moisture retention capacity, regularize soil pH and supply other soil macro and micro nutrients essential for effective crop growth and yield which all enhances nutrient uptake and efficient utilization (Azeez, 2009). Other than nitrogen, animal manure (especially cattle manure) application also provides most of the other essential macro and micro nutrients required for effective crop growth. It is, therefore, a safe and effective way of recovering lost plant nutrients. Plant available phosphorus and potassium for example, are known to be quite high in manures and manure application is known to increase their levels in the soil (Zhou *et al.*, 2012). The increase availability of the macro and micro nutrients ultimately enhances the crop uptake of these nutrients and thus grain yield. However, only a small fraction of animal manure nutrients is immediately available for plant uptake and use; thus, it is required to supply soil with both mineral fertilizers and cattle manure for high plant growth and maximum yields (Sogbedji *et al.*, 2006). As a result of their low nutrient content, in particular nitrogen and slow release of nutrients, animal manure alone cannot meet crop nutrient demand. Other studies have also concluded that the combined application of mineral and organic fertilizers, using methods that best conserve organic matter may be the most promising strategy for improving soil fertility (Sogbedji *et al.*, 2006).

2.8 Combined effect of animal manure and inorganic fertilizers

Soil nutrient management is an important factor for achieving the potential yield in maize production systems because mineral nutrients are the major contributors to increasing crop production and maintenance of soil productivity (Khoshgoftarmanesh and Eshghizadeh, 2011). Finding the best nutrient management approaches that promote efficient nutrient utilization is very essential both for economic and environmental reasons. Combination of chemical fertilizers with organic materials such as cattle manure is a recommended strategy to enhance efficient utilization of soil nutrients by crops (Yadav *et al.*, 2000). Manure nutrients are stored for a longer time in the soil, thereby supporting better root development, leading to higher soil microbial biomass and increased crop yields (Abou El-Magd *et al.*, 2006). Manure serves as a source of all necessary macro and micronutrients in available forms and, therefore, directly affect plant growth. Animal manure nutrients are, however, released slowly during the course of the cropping season due to its high C/N ratio (Mugwe *et al.*, 2007).

To meet maize crops nutrient demand, supply of nutrients from the manure can be complemented by combining them with inorganic fertilizers that will release nutrients faster to compensate for the late release of mineral nutrients of the manure (Ayoola and Makinde, 2009). Research by Nyamangara *et al.* (2003) showed that combinations of organic resources and mineral fertilizers result in greater crop yields. Making most efficient use of animal manures depends critically on improving synchrony of mineralization with crop uptake (Rufino *et al.*, 2006). Mineral N fertilizers applied along with cattle manure can provide sufficient N to crops early in the season, and when accompanied later in the season by a sustained release of N from mineralization of the cattle manure incorporated prior to seeding, the two sources can meet the peak of N demand of the crop (Kramer *et al.*, 2002). Alemu and Bayu (2005) reported yield advantages from the integrated application of farmyard manure and mineral fertilizer on sorghum could possibly be attributed to the additive nutrient supply and to a better synchrony of nutrient availability with crop demand, i.e., the immediate availability of nutrients from mineral fertilizers and slow release from FYM.

2.9 Response of maize to fertilizer application

Soil fertility varies considerably at the farm and landscape levels in many smallholder farming systems in Africa, leading to variable crop productivity and crop response to additions of fertilizer and organic nutrient resources (Zingore *et al.*, 2007). A high N application rate leads to more rapid leaf area development, prolongs leaf life, improves leaf area duration after flowering, and increases overall crop assimilation, thus contributing to increased yield in maize (Balasubramaniyan and Palaniappan, 2001). Phosphorus significantly increases the number of cobs per plot, 1000-grain weight, and grain yield over the control (Qasim *et al.*, 2001). Phosphorus affects leaf growth and senescence dynamics in maize (*Zea mays* L.), and its deficiency slows down the rate of leaf appearance and reduces the final leaf area located below the main ear by 18 to 27 % (Colomb *et al.*, 2000). In a K-deficient soil, crop yield is reduced and N and P response will be small (Balasubramaniyan and Palaniappan, 2001). Potassium, a primary macro nutrient, helps in the translocation of manufactured food, has a stimulating effect on growth and development, and grain yield in maize (Davis *et al.*, 1996). Its application has nascent effect on growth and development (Bukhsh *et al.*, 2011) and grain yield in maize (Bukhsh *et al.*, 2009). According to Wolf (1999), K deficiency typically results in stunted plants with weak stalks that lodge easily.

MATERIALS AND METHODS

3.1. Description of the study area

The research was conducted in the Wenchi Municipality in the Brong-Ahafo Region between August and December, 2020. The municipality is located in the western part of Brong-Ahafo Region and lies within latitudes 7° 30' and 8° 05' North and longitudes 2° 15' West and 1° 55' East. It covers a total land area of 1,145 square kilometers and shares boundaries with Techiman Municipal to the west, Kintampo South District to the northwest, Tain District to the east and Sunyani Municipal to the south. Temperature in the municipality is generally high, averaging about 24.5 °C. Average maximum temperature is 30.9 (°C) and the minimum is 21.2 (°C). The hottest months are February to April. The municipality has two main seasons - rainy and dry seasons. The rainy

season occurs between April to October. The average annual rainfall is between 1,140 to 1,270 mm. The dry season occurs between or from November and February. The Municipality falls within the moist-semi-deciduous forest and the Guinea Savannah woodland vegetation zones. Timber species like odum, sapele, wawa and mahogany are found in places such as Nwoase.

3.2. Experimental treatments

Five (5) treatments were tested in a field experiment as listed below:

- ✓ T1= Control
- ✓ T2= NPK
- ✓ T3= NPK + S + Mg + Ca+ B + Cu + Mo+ Zn
- ✓ T4= Manure (containing N, P₂O₅, K₂O, Ca, Mg, Fe, Zn, Pb, Ni and Cd)
- ✓ T5= T3 + Manure

3.3. Experimental layout/design and crop establishment

The site for the experiment was cleared manually, ploughed and weeded before plots were marked and demarcated. The plots of 5 × 5 m² were laid out in a randomized complete block design (RCBD) with four replicates. Alleys of 1.0 m and 2.0 m were left between plots and replicates respectively to prevent treatment drifts to adjacent plots. The test crop was Lake 601 maize variety. Two maize seeds were sown per hill at a depth of about 3-5 cm at 75 x 50 cm spacing. Weeding was done manually with hoe to keep the fields free from weeds. In all fertilizer applications, point placement was used in order to conserve the nutrients for effective plant use.

The primary nutrients (NPK) were applied in separate proportions- N was applied in the form of urea, P in the form of Triple superphosphate and K in the form of Muriate of potash. One part (60 kg/ha) of the N was applied as urea 2 weeks after planting with the remaining part (30 kg/ha) applied 6 weeks after planting. Full rates of the phosphorus (60 kg P₂O₅/ha) and potassium (60 kg K₂O/ha) were applied as Triple superphosphate and Muriate of potash respectively at 2 weeks after planting. Manure (cow dung) was applied at 6000 kg/ha. Zinc (Zn) was applied as Zinc sulphate (ZnSO₄) at 2.5 kg Zn/ha. Sulphur (S) and Magnesium (Mg) were applied in the form of Kieserite at 6 KgS/ha and 7.5 KgMgO/ha respectively. Calcium (Ca) was applied in the form of Nitabor at 10 KgCaO/ha. Boron was also applied in the form of Nitabor at 1.5 KgB/ha.

3.4. Data collection

Data for the research was collected after harvesting. Specifically, data were collected on the following;

- i. **Total number of plants:** The total number of plants on each plot (per treatment) were counted and noted.
- ii. **Stalk weight (kg):** After harvesting, 20 stalks from each plot (per treatment) were picked, dried and weighed.
- iii. **Hurst weight (kg):** The hurst weight for all harvested plants (per treatment) was weighed.
- iv. **Cob weight (kg):** This was achieved after dehusking the maize. Afterwards, the cobs were weighed for each experimental plot (per treatment).
- v. **Grain weight (kg):** Selected plants within the middle row of each plot were used. After harvesting, the grains are removed from the cobs and dried to a moisture level of 13 %. Afterwards, the seeds are weighed per plot and recorded.

- vi. **Agronomic efficiency:** This will be determine using the formulae, $NUE = \Delta Y / \Delta Q$; where ΔY = change in yield increase and ΔQ = change in qty of nutrients used.
- vii. **Economic Viability (EV) Economic Benefit Cost Ratio (EBCR):** This will be determined using the formulae, $EV = \Delta Y (p) / C$; where ΔY = change in yield increase; p = price of the produce at harvest / kg and C = cost of fertilizer used.

3.5. Statistical analysis

Data was analyzed with analysis of variance (ANOVA) on all measured parameters. Means for each parameter were separated by the least significant difference (LSD) method at 5 % level of significance.

UNDER PEER REVIEW

RESULTS

4.1 Dry shoot weight

There was high significant difference ($P < 0.05$) among the individual treatments with respect to their effect on the dry shoot weight. Specifically, T3 (NPK + Sec_MN) recorded the highest (3.875) dry shoot weight followed by T2 (2.76), T5 (2.7), T4 (2.61) and T1 (2.53) as illustrated in Figure 1.

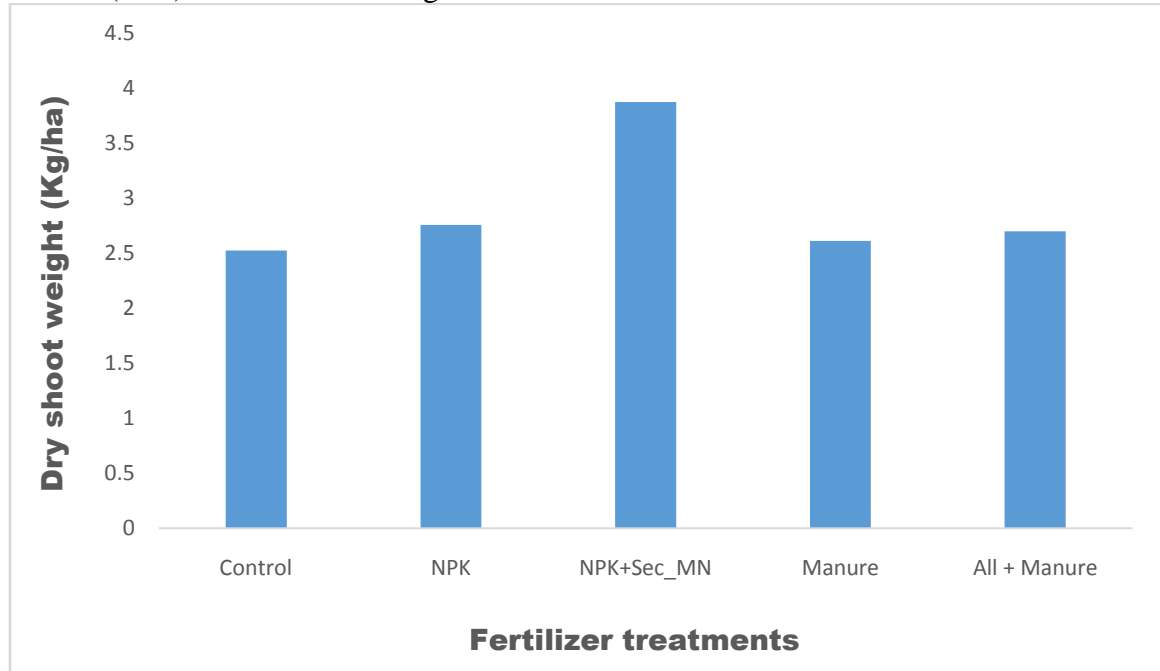


Figure 1: Effect of the treatments on dry shoot weight

4.2 Grain weight

With respect to the grain weight, there was a significant difference ($P < 0.05$) among the individual treatments. The highest (7.17) grain weight was recorded by T3 (NPK + Sec_MN) with the least (1.72) being recorded by T1 (Control). The other treatments recorded 4.75, 4.60 and 5.61 for T2 (NPK), T4 (Manure) and T5 (All + Manure) respectively (Figure 2).

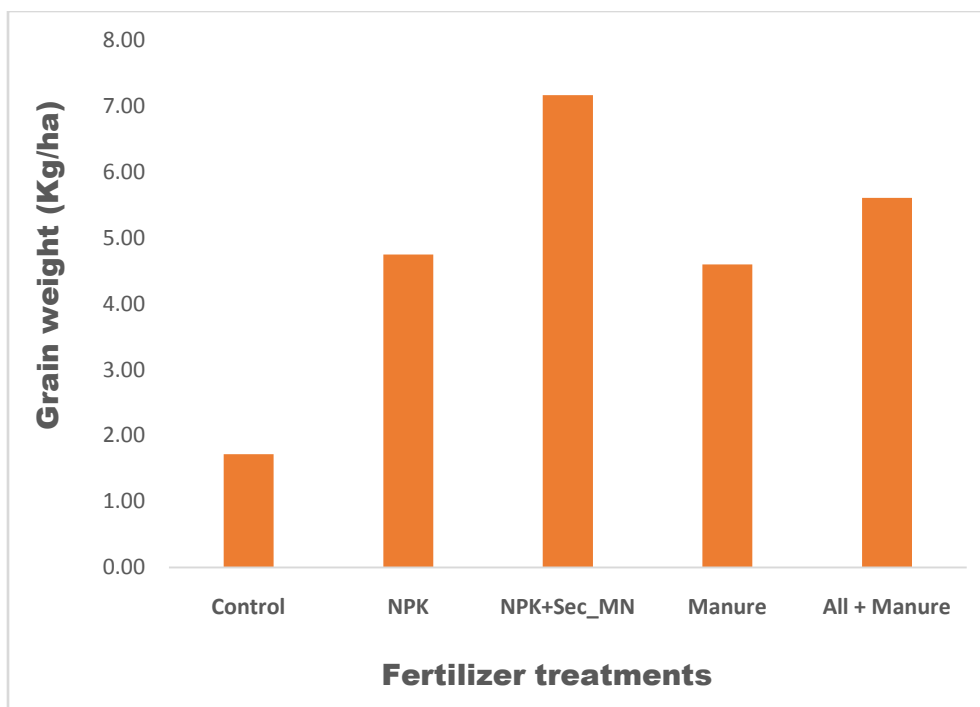


Figure 2: Effect of the treatments on grain weight

4.3 Agronomic efficiency

The research also looked at the Agronomic efficiency of the individual treatments. The control treatment (T1) was used as a common ground (basis) to judge the efficiency of the other treatments (T2, T3, T4 and T5). From the analysis, Duncan's multiple range test for T1, T2, T3, T4 and T5 were 1722, 4935, 7172, 4604 and 7172 respectively. Using the table (from Appendix 1) as the basis for calculation, $NUE = \Delta Y / \Delta Q$; where ΔY = change in yield increase and ΔQ = change in qty of fertilizer used. The results revealed no significant difference ($P > 0.05$) among the individual treatments with respect to their agronomic efficiency. Generally, T3 (NPK + Sec_nutrients) recorded the highest efficiency (24.5 ± 12.47) compared to the other treatments. This was because, on average, for every 1kg of NPK and secondary nutrients applied, 24.5 ± 12.47 kg maize was realized. The implication of this results is that it is more efficient to combine both NPK and secondary nutrients in maize production compared to the other treatments.

Table 4: Agronomic efficiency of the individual treatments

Treatments	Replications				Mean (kg)
	Rep 1	Rep 2	Rep 3	Rep 4	
T2 (NPK)	14.0	8.9	19.4	18.9	15.3 ± 4.93
T3 (NPK + Sec_nutrients)	18.6	18.6	17.6	43.2	24.5 ± 12.47
T4 (Manure)	13.6	3.7	9.9	15.4	10.6 ± 5.18
T5 (NPK + Sec_nutrients + Manure)	7.6	7.3	4.2	11.0	7.6 ± 2.78

4.4 Economic Viability (EV)

Economic viability (EV) is an important index used to evaluate the likely profitability of a practice or product. In this research, the individual treatments were assessed to know

their economic implications when adopted. Like in the NUE, The control treatment (T1) was used as a common ground (basis) to judge the profitability in using the other treatments (T2, T3, T4 and T5). The results revealed that there was no significant difference ($P > 0.05$) among the individual treatments with respect to their economic viability (EV). However, T3 (NPK + Sec_nutrients) proved to be more economically feasible (GH¢ 9.2 ± 4.7). The implication of this results is that for every 1 kg of T3 (NPK + Sec_nutrients) that was used, an amount of GH¢ 9.2 ± 4.7 will be realized. This was the highest compare to T2 (GH¢ 6.1 ± 2.0), T4 (GH¢ 2.5 ± 1.2) and T5 (GH¢ 2.2 ± 0.8).

Table 5: Economic viability of the individual treatments

Treatments	Replications				Mean (GH¢)
	Rep 1	Rep 2	Rep 3	Rep 4	
T2 (NPK)	5.6	3.6	7.8	7.6	6.1 ± 2.0
T3 (NPK + Sec_nutrients)	7.0	7.0	6.6	16.2	9.2 ± 4.7
T4 (Manure)	3.2	0.9	2.3	3.6	2.5 ± 1.2
T5 (NPK + Sec_nutrients + Manure)	2.2	2.1	1.2	3.2	2.2 ± 0.8

DISCUSSION

5.1 Effect of NPK + Sec_MN on the performance of maize

From the results gathered, it was realized that the application of NPK + Sec_MN had a more positive impact on most parameters assessed in the study. Specifically, NPK + Sec_MN produced promising performances with respect to its effect on stalk weight, hurst weight, cob weight and grain weight compared to the other treatments. The high performance of T3 (NPK + Sec_MN) could be attributed to the secondary nutrients that were added to the NPK. Similarly, several studies have revealed the need for the application of various nutrient elements such as nitrogen (N), phosphorus (P), potassium (K), sulphur (S), and some trace (secondary) elements in order to boost crop productivity (Ayodele and Omotosho, 2008; Adekayode and Ogunkoya, 2010). The use of micronutrients increased the yield and also uptake of nutrients when applied in combination with macronutrients as compared to conventional fertilization which lack micronutrients (Bakry *et al.* 2009; Singh *et al.* 2009; Azhar, 2011). Isitekhale *et al.*, (2013) also made a similar assertion. Likewise, Tisdale, (1984) reported on the significance of some secondary nutrients in the performance of maize. Marschner, (1995) and Cakmak, (2000) also stressed that secondary nutrients such as Zn and S are extremely important and required for regulation and maintenance of the gene expression to induce tolerance of environmental stresses in plants (Cakmak, 2000).

Xia *et al.*, (2004) opined that nitrogen integrated with zinc improved plant height and yield in maize. Adetunji and Adepetu, (1989) equally testified the importance of S in plant growth. This statement is further supported by Choudhary and Das, (1996) who reported that S provides beneficial effects by lowering soil pH and improving physical conditions of the soil. Muthukumararaja and Sriramachandrasekharan *et al.*, 2012 reported that the application of NPK with micronutrients significantly improved the availability of native and applied macro and micronutrients in the soil which subsequently increased grain yield of maize. Zinc (Zn) is also considered as an important secondary nutrient essential for plant growth (Kumar *et al.*, 2012). According to Brown *et al.*, (1993), formation of male and female reproductive organs and pollination process are disturbed when Zn is deficient. It is required in a large number of enzymes and plays an essential role in DNA transcription (Kumar *et al.*, 2012). Other functions of zinc include: catalyzing the process of oxidation in plant cell and is vital for the transformation of carbohydrates; and influencing the formation of chlorophyll and auxins, the growth promoting compounds (Mamatha, 2007).

5.2 Assessment of Nutrient Use Efficiency (NUE) and Economic Viability (EV) as affected by different nutrients (and nutrient combinations).

The beneficial effects of fertilizer application on soils for a sustainable food crop production has made the need for information in fertilizer supply and use for increased food production desirable (Adekayode and Ogunkoya, 2010). Grain yield is the final product of many yield-contributing components, from physiological processes to morphological development which take place in plants during growth and development stages. This same component also determines the income of the farmer. Determining the profitability of fertilizer requires comparing the costs of applying fertilizer with the value of output that it generates. The results obtained from the field experiment indicated that it was more efficient to combine both NPK and secondary nutrients in maize production compared to using only NPK; such that, the combined effect gave more yield and

subsequently generated more money (income). Morris *et al.*, (2007) and Kelly (2006) both examined fertilizer profitability in SSA using this method. Morris *et al.*, (2007) found that fertilizer tends to be profitable for maize farmers in West Africa, yet less than half of maize farmers in Ghana apply fertilizer. This, they blamed to the fact that most farmers make their fertilizer application decision based on profitability. Thus, the low fertilizer application (especially NPK) by most maize farmers could be related to the relatively low returns they get after harvest. Vegetative growth and consequently biological yield are highly dependent on consumption of micro and macro chemical elements by the maize plant (Ehsanullah *et al.*, 2015). By implication, the application of fertilizers that contain those important elements required by the maize plant leads to a substantial increase in biological yield and a subsequent improvement in income levels. Thus, it will be appropriate to suggest that the addition of the secondary nutrients will make a huge difference as depicted by the results from the present-day study. A previous report showed that application of elemental S at a rate of 0.5 g S kg^{-1} soil decreased soil pH value from 7.03 to 6.29 and significantly increased availability of Mg and Zn which resulted in a 45 % increase in total yield (Karimizarchi *et al.*, 2014).

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Although the application of NPK alone had a substantial increase on the yield and yield parameters of maize, it was the combined application of the secondary nutrients and NPK that made the difference in the research. The findings showed that the combine effect of secondary nutrients (S + Mg + Ca+ B + Cu + Mo+ Zn) and NPK had a very positive impact on the stalk weight, hurst weight, cob weight and grain weight. In almost all the parameters assessed, the control treatment proved the need for the application of fertilizer to obtain maximum yield.

6.2 Recommendations

Based on the results obtained in the research, the following recommendations have been suggested;

- i. With the combination of the secondary nutrients and NPK giving more promising results compared to the other treatments, the research recommends that much attention should be given to this particular treatment. Possibly, different doses of this treatment should also be analyzed to know the actual extent at which the secondary nutrients and the NPK can be combined to give the maximum yield.
- ii. Also, similar research should be staged at a different location to know whether similar results would be obtained. This is because soil and climatic conditions can as well affect plants' ability to effectively absorb and utilize available nutrients. By implication, the research sought to know whether the performance of T3 (NPK + Sec_MN) was not soil or climatic bound.

REFERENCES

- Abou El- Magd, M., Hoda, M., Mohamed A., and Fawzy, Z. F. (2006). Relationship growth, yield of broccoli with increasing N, P or K ratio in a mixture of NPK fertilizers (*Brassica oleracea* var *italica* plenck). *Annals of Agriculture Science, Moshtohor.* vol. 43(2): 791-805.
- Adekayode, F. O., and Ogunkoya, M. O. (2010). Effect of quantity and placement distances of inorganic 15-15- 15 fertilizer in improving soil fertility status and the performance and yield of maize in a tropical rain forest zone of Nigeria. *America-Eurasian J. Agric. And Environ. Sci.*, 7(2): 122-129.
- Adetunji, M. T. (1991). Effect of lime and phosphorus application on the sulphate adsorption capacity of southwestern Nigerian soils. *Ife J. Agric. Res.* **13**: 11- 20.
- Adetunji, M. T., and J., Adepetu A. (1989). Sulphur fertilization requirements of Southwestern Nigerian soils. *Ife J. of Agric Res.*, 11: 23-30.
- Adetunji, M. T., and Adepetu J. A. (1989). Sulphur fertilization requirements of Southwestern Nigerian soils. *Ife J. of Agric Res.*, 11: 23-30.
- Khoshgoftarmanesh, A. H., Eshghizadeh H. R. (2011). *Communications in soil science and plant analysis.* 42 (10), 1200-1208.

- Akande, M. O., Makinde, E. A., Oluwatoyinbo, F. I., and Adetunji, M. T. (2010). Effects of phosphate rock application on dry matter yield and phosphorus recovery of maize and cowpea grown in sequence. *Afr. J. Environ. Sci. Technol.*, 4(5): 293-303.
- Akmal, M., S. M., Shah, M. Asim and M. Arif. (2011). Causes of yield reduction by delayed planting of hexaploid wheat in Pakistan. *Pak. J. Bot.* 43 (5):2561-2568.
- Alemu, G., and Bayu, W. (2005). Effects of farmyard manure and combined N and P fertilizer on sorghum and soil characteristics in Northeastern Ethiopia. *J. Sustain. Agr.* 26(2):23-40.
- Alloway, B. J. (2008). Zinc in soils and crop nutrition. International Zinc Association Communications. Brussel: IZA Publications.
- Andrade, H., Du, Y., and Wang, X. (2002). Putting rubrics to the test: The effect of a model, criteria generation, and rubric-referenced self-assessment on elementary school students' writing. *Educational Measurement: Issues and Practices*, 27 (2), 3–13.
- Ayodele, O. J., and Omotosho, S. O. (2008). Nutrient management for maize production in soils of the savannah zone of southwestern Nigeria. *International Journal of Soil Science*, 3: 20-27.
- Ayoola, O. T., and Makinde, E. A. (2009). Maize growth, yield and soil nutrient changes with n-enriched organic fertilizers. *American Journal of Food, Agricultural, Nutrition and Development*, 9 (1), 580–592.
- Azeez, J. O. (2009). Effects of nitrogen application and weed interference on performance of some tropical maize genotypes in Nigeria. *Pedosphere* 19 (5): 654-662.
- Azhar G. (2011). Influence of Integrated Nutrients on Growth, Yield and Quality of Maize (*Zea mays* L.). *Am. J Plant Sci.* 2011; 2:63-69.
- Bakht, J., Ahmad, S., Tariq, M., Akbar H., and Shafi. M. (2006). Response of maize to planting methods and fertilizer nitrogen. *J. Agric. Biol. Sci.*, 1: 8-14.
- Bakry, M. A., Soliman, Y. R., Moussa, S. A. (2009). Importance of micronutrients, organic manure and bio-fertilizer for improving maize yield and its components grown in desert sandy soils. *Res. J Agric. and Biol. Sci.* 2009; 5:16-23.
- Balasubramaniyan, P., and Palaniappan, S. P. (2001). Principles and practices of agronomy. 185 p. Agrobios, Jodhpur, India.
- Balemi, T., Negisho, K. (2012). Management of soil phosphorus and plant adaptation mechanisms to phosphorus stress for sustainable crop production: a review. *J. Soil Sci. Plant Nutr.* 12, 547–561.
- Bar-Tal, A., Aoni, B., Karni, L., and Rosenberg, R. (2001). Nitrogen nutrition of greenhouse pepper: Effects of nitrogen concentration and NO₃: NH₄ ratio on growth, transpiration and nutrient uptake. *Hort. Sci.* 2001; 36(7): 1252-1259.
- Bashir, M. K. (2012). The determinants of rural household food security in the Punjab, Pakistan: an econometric analysis. Working paper 1203, School of Agricultural and Resource Economics, University of Western Australia, Crawley, Australia.
- Belfield, S. and Brown, C. (2008). Field crop manual: Maize a guide to upland production in Cambodia. Nwe South Wales, UK.

- Birch, L. L., Fisher, J. O., and Davison, K. K. (2008). Learning to overeat: maternal use of restrictive feeding practices promotes girls' eating in the absence of hunger. *The American Journal of Clinical Nutrition*, 78, 215–220.
- Blumenthal, J., Battenspenrger, D., Cassman, K. G., Mason, K. G., and Pavlista, A. (2008). Importance of nitrogen on crop quality and health. In: Hatfield JL, Folett RF, editors. *Nitrogen in the Environment: Sources, Problems and Management*, 2nd. Elsevier, Amsterdam, 2008.
- Borrás, L., and Westgate, M. E. (2006). Predicting maize kernel sink capacity early in development. *Field Crops Research* 95, 223–233.

UNDER PEER REVIEW

- Bourdillon, M., Hebinick, P., Hoddinott, J., Kinsey, B., Marondo, J., Mudege, N., and Owens, T. (2003). Assessing the impact of high-yielding varieties of maize in resettlement areas of Zimbabwe. International Food Policy Research Institute, Washington, D.C.
- Brady, N. C., and Weil, R. R. (2008). *The Nature and Properties of Soils*. Revised 14th ed. Pearson Prentice Hall. New Jersey, 2008.
- Brady, N. C., (1984). *The Nature and Properties of Soils*, Macmillan Publishing Company, New York, NY, USA, 1984.
- Braimoh, A. K. and Vlek, P. L. G. (2006). Soil Quality and Other Factors Influencing Maize Yield in Northern Ghana. *Soil Use and Management* 22 (2), 165–171.
- Breman, H., Debrah, S. (2003). Improving African food security. *SAIS Rev.* 23 (1), 153–170.
- Brown, P. H., Cakmak, I., Zhang, Q. (1993). Forms and function of zinc in plants. Zinc in soils and plants. In: A.D. Robson (ed). Kluwar Academic Publishers, Dordecht, The Netherlands, 1993, 93-1.6.
- Brown, W. L. and Darrah, L. L. (1985). *Origion, Adaptation and Types of Corn*. Cooperative Extension Service. Iowa State University. Ames, Iowa 50011.
- Bukhsh, M. A. A. H. A., Ahmad, R., Iqbal, J. (2011). Nutritional and physiological significance of potassium application in maize hybrid crop production. *Pakistan J Nutri.* 2011;11(2):187–202.
- Bukhsh, M. A. A. H. A., Ahmad, R. Chema, Z. A. and Ghafoor, A. (2009). Production potential of three maize hybrids as influenced by varying plant density. *Pakistan J. Agri. Sci.* 45(4): 413-417.
- Buresh, R. J., Smithson, P. C. and Heliums, D. T. (1997). Building soil phosphorus capital in Africa, p. 111-149. In R.J. Buresh *et al.*, (ed.) *Replenishing soil fertility in Africa*. SSSA Spec. Publ. 51. SSSA, Madison, WI (this publication).
- Cakmak, I. and Yazici, A. M. (2010). Magnesium: A forgotten element in crop production. *Better Crops.* 2010; 94 (2): 1-3.
- Cakmak, I. (2000). Possible roles of zinc in protecting plant cells from damage by reactive oxygen species. *New Phytol.* 146:185–205.
- Campillo, R. Claudio, J. and Pablo, U. (2010). Effects of nitrogen on productivity, grain quality, and optimal nitrogen rates in winter wheat cv. Kumpa-inia in andisols of Southern Chile. *Chilean Journal of Agricultural Research* 2010; 70(1): 122- 131.
- Capdevillea, G. D., Maffiab, L. A., Fingerc, F. L., and Batistab, U. G. (2005). Pre-harvest calcium sulfate applications affect vase life and severity of gray mold in cut roses. *Hort.* 2005; 103: 329–338.
- Cazetta, J. O., Seebauer, J. R., Below, F. E. (1999). Sucrose and nitrogen supplies regulate growth of maize kernels. *Annals of Botany* 84, 747–754.
- Chaturvedi, I. (2005). Effect of nitrogen fertilizers on growth, yield and quality of hybrid rice (*Oryza sativa*). *J. Cent. Eur. Agri.* 2005; 6(4): 611-618.
- Chaudhary, A. (1983). *Maize in Pakistan*, Punjab Agri. Research Coordination Board Univ of Agri Faisalabad.
- Choudhary, H. P., and Das, S. K. (1996). Effect of P, S and Mo application on yield of rain-fed blackgram and their residual effect on safflower and soil and water conservation in eroded soil. *J. Indian Soc. Soil Sci.*, **44**: 741-745.

- Ciampitti, I. A., Vyn, T. J. (2011). Physiological perspectives of changes over time in maize yield dependency on nitrogen uptake and associated nitrogen efficiencies: a review. *Field Crop. Res.* 133, 48–67.
- Colomb, B., Debaeke, P., Jouany, C., Nolot, J. M. (2000). Phosphorus management in low input stockless cropping systems: Crop and soil responses to contrasting P regimes in a 36-year experiment in southern France, *European Journal of Agronomy*, 10.1016/j.eja.2006.09.004, **26**, 2, (154-165), (2000).
- Conolly, E. L., and Guerinot, M. L. (2002). Iron stress in plants. *Gen. Biol.* 2002; 3(8): 1-4.
- Davis, J. G., Walker, M. E., Parker, M. B. and Mullinix, B. (1996). Long term phosphorus and potassium application to corn on Coastal Plain soils. *Journal of Production Agriculture* 9:88-94.

UNDER PEER REVIEW

- Di Masso, A., Dixon, J., and Hernández, B. (2017). Place attachment, sense of belonging and the micro-politics of place satisfaction. In G. Fleury-Bahi, E. Pol, and O. Navarro (Eds.). Handbook of environmental psychology and quality of life research (pp. 85–104). Dordrecht: Springer.
- Echarte, L., Rothstein, S., and Tollenaar, M. (2008). The response of leaf photosynthesis and dry matter accumulation to nitrogen supply in an older and a newer maize hybrid. *Crop Sci.* 48, 656–665.
- Edward J. (2009). Maize growth and development. New South Wales, Orange, 50 p.
- Efe, L., and Yapuzi, E. (2011). The effect of zinc application methods on seed cotton yield, lint and seed quality of cotton (*Gossypium hirsutum* L.) In east Mediterranean region of Turkey. *African Journal of Biotechnology.* 2011; 3(8): 1-4.
- Ehsanullah, T. A., Randhawa, M. A., Anjum, S. A., Nadeem, M., and Naeem, M. (2015). Exploring the role of zinc in maize (*Zea mays* L.) through soil and foliar application. *Universal Journal of Agricultural Research*, 3 (3), 69-75.
- Enyisi, I., Umoh, V., Whong, C., Abdullahi, I., and Alabi, O. (2014). Chemical and nutritional value of maize and maize products obtained from selected markets in Kaduna State, Nigeria. *Afr. J. Food Sci. & Technol.*, 5 (4): 100-104.
- Falk KL, Tokulisa JG and J Gershenzon The effect of sulphur nutrition on plant glucosinolate content: Physiology and molecular mechanisms. *Plant Biol.* 2007; 9:573-581.
- Food and Agriculture Organization of the United Nations (FAO). (2014). Sampling Methods for Agricultural Surveys. FAO Statistical Development Series 3. Rome.
- Foth, H. D., and Ellis, B. G. (1988). Soil fertility. New York: Wiley.
- Fuertes-Mendizábal, T., González-Torralba, J., Arregui, L. M., González Murua, C., Estavillo, J. M., and González-Moro, M. B. (2012). Ammonium nutrition affects the accumulation of winter wheat glutenins. Proceedings of the 17th International Nitrogen Workshop on Innovations of Sustainable use of nitrogen resources, 2012.
- Gangamrutha, G. V. (2008). Effect of copper nutrition on yield and quality of chilli in a Vertisol of Zone-8, Karnataka. MSc Thesis. Dharward University, India. 2008.
- Grotz, N., and Guerinot, M. L. (2002). Molecular aspects of Cu, Fe and Zn homeostasis in plants. *Biochim Biophys Acta.* 2002; 1763(7): 595-608.
- Hammad, H. M., Ahmad, A. F., Azhar, T., Khaliq, S., Wajid, A., Nasim, W., and Farhad. W. (2011). Optimizing water and nitrogen requirement in maize (*Zea mays* L.) under semiarid conditions of Pakistan. *Pak. J. Bot.* 43:2919-2923.

- Hammami, A., Rezgui, S., and Hellali, R. (2010). Leaf nitrogen and potassium concentrations for optimum fruit production, quality and biomass tree growth in Clementine mandarin under Mediterranean climate. *Journal of Horticulture and Forestry*. 2010; 2(7): 161-170.
- Haque, M. M., Hamid, A., and Bhuiyan, N. I. (2001). "Nutrient uptake and productivity as affected by nitrogen and potassium application levels in maize/sweet potato intercropping system", *Korean Journal of Crop Sciences*, 46(1), 1-5.
- Hasani, M., Zamani, Z., and Fatahi, R. (2012). Effects of zinc and manganese as folia spray on pomegranate yield, fruit quality and leaf minerals. *Journal of Soil Science and Plant Nutrition*. 2012; 12(3): 471-480.
- Havlin, J. L., Beaton, J. D., Tisdale, S. L., and Nelson, W. L. (2005). *Soil Fertility and Fertilizers: An Introduction to Nutrient Management*. 7th (ed.). Pearson Prentice Hall. New Jersey, 2005.
- Hermans, C., Johnson, G. N., Strasser, R. J., and Verbruggen, N. (2004). Physiological characterization of magnesium deficiency in sugar beet: acclimation to low magnesium differentially affects photosystem I and II. *Plants*. 2004; 220: 344-355.
- Hitchcock, A. S., and Chase, A. (1971). *Manual of the grasses of the United States*. 2nd edition. Dover, New York. Pp 1865 – 1935.
- Hoyum, R. (2000). Magnesium builds potato profits and quality. *Fluid Journal*. 2000.
- Hughes, S. (2006). *Black hands in the biscuits not in the classrooms: Unveiling hope in a struggle for Brown's promise*. New York: Peter Lang.
- Hussaini, M. A., Ogunlela, V. B., Ramalan, A. A., and Falaki, A. (2008). Mineral composition of dry season maize (*Zea mays* L.) In response to varying levels of Nitrogen, phosphorus and irrigation at Kadawa, Nigeria. *W. J. Agri. Sci.* 2008; 4(6): 775- 780.
- IFBC. (1990). International Food Biotechnology Council. *Biotechnologies and food: assuring the safety of foods produced by genetic modification*. *Regulatory Toxicology and Pharmacology* 12: S1-S196.
- Isitekhale, H. H. E., Aboh, S. I., and Oseghale, E. S. (2013). Sulphur Status of Some Soils in Edo State, Nigeria. *Int. J. Scientific Technol. Res.*, 2(5): 91-95.
- Islam, M. N., Hoque, S., and Islam, A. (2006). Effect of P and S interactions on nutrient concentration and yield of wheat, rice and mungbean. *J. Indian Soc. Soil Sci.*, 54:86-91.
- ITTA (2009). *Maize Research and Impact*. International Institute of Tropical Agriculture.
- Jaliya, M. M., Chiezey, U. F., Tanimu, B., Odunze, A. C., Othman, M. K., Babaji, B. A., Sani, B. M., and Mani, H. (2012). Effects of Nitrogen and Sulfur fertilizers on Nitrogen content in soil, ear leaf, flag leaf and grain of QPM maize varieties at Samaru Zaria. *Journal of Agricultural Science*, 4(5): 217-222.
- Jifon, J. L., and Lester, G. E. (2009). Foliar potassium fertilization improves fruit quality of field grown muskmelon on calcareous soils in South Texas. *J. Sci. of Food Agri.* 2009; 89(14): 2452-24-60.
- Kabata-Pendias, A. and Pendias, H. (2011) *Trace Elements in Soils and Plants*. 4th Edition, CRC Press, Boca Raton.
- Karimizarchi, M., Aminuddin, H., Khanif M. Y., and Radziah, O. (2014). Elemental Sulphur Application Effects on Nutrient Availability and Sweet Maize (*Zea mays*

- L.) Response in a High pH Soil of Malaysia. *Malaysian Journal of Soil Science*. 18: 75-86.
- Kelly, V. A. (2006). *Factors Affecting Demand for Fertilizer in Sub-Saharan Africa*. Washington, D.C.: World Bank.
- Kling, J. G., Oikeh, O. S., and Okuruwa, A. E. (1998). Nitrogen fertilizer management effects on maize grain quality in West Africa moist Savanna. *Crop Science*. 1998; 58:1056-1061.
- Kramer, R., Michalowski, R., Kauzlarich, D (2002) The origins and development of the concept and theory of state-corporate crime. *Crime Delinq* 48:263–282.
- Kumar, S. A. M., Meena, M. K., and Upadhyaya, A. (2012). Effect of Sulphur and Zinc on Rice Performance and Nutrient Dynamics in Plants and Soil of Indo Gangetic Plains. *J. Agri. Sci.* 2012; 4(11).
- Kumawat, B. L, Pathan, A. R. K., and Chahan, R. (2004). Response of taramirra to sulphur and phosphorus application on Typic Pasmmt. *J. Indian Soc. Soil Sci.*, 52: 476-478.
- Lafitte, H. R. (2000). Abiotic stresses affecting maize. In: RL Paliwal, G Granados, HR Lafitte, AD Vlolc, eds. *Tropical Maize: Improvement and Production*. Food and Agriculture Organization of the United Nations Rome. pp 93-103.
- Launaskas, J., and Kvikliene, N. (2006). Effect of calcium foliar application on some fruit quality characteristics of ‘Sinap Orovskij’ apple. *Agron. Res.* 2006; 4(1): 31-36.
- Lester, G. E, Jifon, J. L., and Makus, D. J., (2010). Impact of potassium nutrition on postharvest fruit quality: melon (*Cucumis melo* L.) Case study. *Plant Soil*. 2010; 335(1): 117-131.
- Ma, B. L. and Subedi, K. D. (2005) Development, Yield, Grain Moisture and Nitrogen Uptake of Bt Corn Hybrids and Their Conventional Near-Isolines. *Fields Crops Research*, 93, 199-211.
- Magani, I. E., and Kuchinda, C. (2009). Effects of phosphorus fertilizer on growth, yield and crude protein content of cow pea (*Vigna Unguiculata* L.Walp) in Nigeria. *J. Appl.Biosci.* 2009; 23: 1387-1393.
- Magani, I. and Kuchinda, C. (2009). Effect of Phosphorus Fertilizer on Growth, Yield and Crude Protein Content of Cowpea (*Vigna unguiculata* (L.) Walp) in Nigeria. *Journal of Applied Bioscience*, 23, 1387-1393.
- Malik, M. A., Farrukh, M., Ali, A., and Mahmood, I. (2003). Effect of nitrogen and phosphorus application on growth, yield and quality of mungbean (*Vigna radiate* L.). *Pak. J. Agri. Sci.* 2003; 4(3): 133-136.
- Mamatha, N. (2007). Effect of sulphur and micronutrients (iron and zinc) on yield and quality of cotton in a Vertisol. Msc Thesis. University of Agricultural Sciences, Dhaward, India. 2007.
- Marschner, H. (1995). *Mineral nutrition of higher plants*. Second edition. 889pp. London: Academic Press, £29.95 (paperback).
- Marschner, H. (1995). *Mineral nutrition of higher plants* (2nd ed.). London: Academic Press.
- Melchiori, R. J. M., Caviglia, O. P. (2008). *Field Crops Research* 108 (3), 198-205.

- MiDA. (2007). Millennium Challenge Account Proposal: Reducing Poverty through Economic Growth. Ghana Proposal for MCA Funding. Final Draft. Millennium Development Authority (MiDA), Accra. Ghana.
- Mikkelsen, R. L. (2005). Tomato flavor and plant nutrition. A brief review. *Better crops*. 2005; 89(2): 14-15.
- Mitra, S. K. (2009). Postharvest Physiology and Storage of Tropical and Subtropical Fruits. CAB International, London, UK., ISBN-13: 9780851992105, pp: 47-78.
- Monjardino, P., Smith, A. G., and Jones. R. J. (2006). Heat stress effects on protein accumulation of maize endosperm. *Crop Sci.* 45:1203–1210.
- Morris, M., Kelly, V., Kopicki, R. J., and Byerlee, D. (2007). *Fertilizer Use in African Agriculture: Lessons Learned and Good Practice Guidelines*. Washington, D.C.: The World Bank.
- Mueller, N. D., Gerber, J. S., Johnston, M., Ray, D. K., Ramankutty, N., Foley, J. A. (2012). Closing yield gaps through nutrient and water management. *Nature* 490 (7419), 254–257.
- Mugwe, J., Mugendi, D., Odee, D., and Otieno, J. (2007). Evaluation of the potential of using nitrogen-fixing legumes in smallholder farms of Meru south district. In *Advances in Integrated Soil Fertility Management in Sub-Saharan Africa: Challenges and Opportunities*, 503–510 (Eds A. Bationo, B. Waswa, J. Kihara and J. Kimetu). Netherlands: Springer.
- Muhammad, I., Muhammad, J. K., Amjad, A. 1., Amanullah, J. and Sajida, P. (2015). Effect of Phosphorus and Sulfur on the yield and nutrient uptake of maize. *International Journal of Farming and Allied Sciences*, 4(3): 244-252.
- Mustonen, A., Niemelä, S., Nordström, T., Murray, G. K., Mäki, P., Jääskeläinen, E., and Miettunen, J. (2012). Adolescent cannabis use, baseline prodromal symptoms and the risk of psychosis. *Br. J. Psychiatry*. 2012; 212:227–233.
- Muthukumararaja, T., and Sriramachandrasekharan M. V. (2012). Effect of zinc on yield, zinc nutrition and zinc use efficiency of lowland rice. *J. Agri. Tech.* 2012; 8(2): 551–561.
- Nadaf, S. A., Chidananduppa, H. M., and Yadahalli, V. (2013). Quality parameters and oil yield of groundnut (*Arachis hypogaea* L.) As influenced by soil application of zinc and boron under sandy loam texture soils of Typic Haplustalf (Shivamgga). *Research Journal of Agricultural Sciences*. 2013; 4(2): 196-198.
- Nielsen, R. L. 2013. Field dry down of mature corn grain.
- Nyamangara, J., M. I. Piha, and Kirchmann, H. (2003). Interactions of aerobically decomposed cattle manure and nitrogen fertilizer applied to soil. *Nutr. Cycling Agroecosyst.* 54:183–188.
- Olaniyan, A. B., Lucas, E. O. (2015). Effect of periodic reduction in density of planting on yield of maize genotypes in south western Nigeria. *Res. Crops J.* 3(2):315-321.
- Onasanya, R. O., Aiyelari, O. P., Onasanya, A., Oikeh, S., Nwilene, F. E., and Oyelakin, O. O. (2009). Growth and yield response of maize (*Zea mays* L.) to different rates of nitrogen and phosphorus fertilizers in southern Nigeria. *World J. Agric. Sci.* 5 (4): 400-407.
- Onimisi PA, Omage JJ, Dafwang II, Bawa GS. 2009. Replacement value of normal maize with quality protein maize (Obatampa) in broiler diets. *Pak J Nutr.* 8:112115.

- Phillips, S. B., Warren, J. G., and Mullins, G. L. (2005). Nitrogen rate and application, timing affects “Beauregard” sweet potato yield and quality. *Hort Science*. 2005; 40(1): 214-217.
- Piperno, D. R., and Flannery, K. V. (2001). The earliest archaeological maize (*Zea mays* L.) from Highland Mexico: New accelerator mass spectrometry dates and their implications. *Proceedings of the National Academy of Sciences, USA* 98(4):2101-2103.
- Qasim, M., Bashir, A., Anees, M. M., Raza, A., Ghani, M. U., Khalid, M., Malik, J., and Hanan, F. (2001). Economic Development in Leather Tannery and Environment Issues. *Bulletin of Energy Economics*, 3(1), 41-47.
- Qasim, M., Himayrull, H., and Subha, M. (2001). Effect of increasing levels of phosphorus and seed rate on the economic yield of maize. *Online Journal of Biological Sciences* 1:40-42.
- Ray, R. W., and Mughogho, S. K. (2000). Sulphur nutrition of maize in four regions of Malawi. *Agronomy Journal*, 92: 649–656.
- Rego, T. J., Sahrawat, K. L, Wani, S. P., Pardhasaradhi, G. (2007). Widespread deficiencies of sulfur, boron and zinc in Indian semi-arid tropical soils: on-farm crop. *J Plant Nutri*. 2007; 30:1569-1583.
- Roy, R. N., Finck, A., Blair, G. J., and Tandon, H. L. S. (2006). *Plant Nutrition for food security: A guide for integrated nutrient management*. FAO Fertilizer and Plant Nutrition Bulletin 16. FAO, Rome, Italy, 2006.
- Rufino, M. C., Rowe, E. C., Delve, R. J., Giller, K. E. (2006). Nitrogen cycling efficiencies through resource-poor African crop–livestock systems. *Agriculture, Ecosystems and Environment* 112, 261–282.
- Rurinda, J., Mapfumo, P., van Wijk, M. T., Mtambanengwe, F., Rufino, M. C., Chikowo, R., Giller, K. E. (2013). Managing soil fertility to adapt to rainfall variability in smallholder cropping systems in Zimbabwe. *Field Crop. Res.* 154, 211–225.
- Rusinamhodzi, L., Corbeels, M., van Wijk, M.T., Rufino, M.C., Nyamangara, J., Giller, K.E., 2011. A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. *Agron. Sustain. Dev.* 31 (4), 657–673.
- Sanchez, P. A. (2015). En route to plentiful food production in Africa. *Native Plants* 1, 14014.
- Shanti, K. V. P., Rao, M. R., Reddy, M. S., Sarma, R. S. (1997). Response of maize (*Zea mays*) hybrid and composite to different levels of nitrogen. *Indian Journal of Agricultural Science*. Vol. 67:424-425.
- Sidkar, M. S. I., Rahman, M. M., Islam, M. S., Yeasmin. M. S., and Akhter, M. M. (2008). Effects of nitrogen level of aromatic rice varieties and soil fertility status. *International Journal of Sustainable Crop Production*. 2008; 3(3):49-54.
- Singh, R. N., Nath, N. N., Singh, S. K., Mohan, T. K., Shahh, J. P. (2009). Effect of agronomic management practices on growth, yield and quality of kharif maize (*Zea mays* L.) under excessive moisture conditions. *Crop Res.* 2009; 32(3):302-305.
- Sogbedji, J. M., Van Es, H. M., and Agbeko, K. L. (2006). Cover cropping and nutrient management strategies for maize production in West Africa. *Agronomy Journal*, 98, 883 889.

- Sylvia, D. M., Furhmann, J. J., Hartel, P. G., and Zuberer, D. A. (2005). *Principles and Application of Soil Microbiology*. 2nd (ed.). Pearson Prentice Hall. New Jersey, 2005.
- Tesfaye, K., Gbegbelegbe, S., Cairns, E.J., Shiferaw, B., Prasanna, B.M., Sonder, K., Boote, K., Makumbi, D., Robertson, R., 2015. Maize systems under climate change in subSaharan Africa: potential impacts on production and food security. *International Journal of Climate Change Strategies and Management* 7 (3), 247–271.
- Tisdale, S. L., Nelson, W.L., and Beaten, J. D. (1984). *Zinc In soil Fertility and Fertilizers*. Fourth edition, New York: Macmillan Publishing Company.
- U.S. Department of Agriculture, Office of the Chief Economist, World Agricultural Outlook Board (USDA, WAOB). *USDA Agricultural Baseline Projections to 2012, Baseline Report OCE-2006-1, February 2006*.
- Uzoh, I. M., Obalum, S. E. and Ene, J. (2015). Mineralization rate constants, half-lives and effects of two organic amendments on maize yield and carbon-nitrogen status of loamy Ultisol in southeastern Nigeria. *Agro-Science*, 14 (3), 35-40.
- Walker, S., and Silva, E. (2008). ‘Nunmex’ sweet onion. New Mexico State University. Department of State Cooperating. 2008.
- Wolf, B. (1999). *The fertile triangle: the interrelationship of air, water, and nutrients in maximizing soil productivity*. New York, USA: Food Products Press.
- Woltz, J. M., Eglin, D. B., and TeKrony, D.M. (2006). Freezing point temperatures of corn seed structures during seed development. *Agron. J.* 97:1564-1569.
- Xia, L., Kent, B., and Monroe, B. (2004), “Comparative Others, Trust, and Perceived Price Fairness,” paper presented at the Annual Conference of Society of Consumer Psychology, San Francisco (February 20).
- Yadav, R. L., Prasad, K., Dwivedi, B. S., Tomar, R. K. and Singh, A. K. (2000). Cropping systems. In G.B. Singh & B.R. Sharma, eds. *Fifty years of natural resource management research*, pp. 411–446. New Delhi, Indian Council of Agricultural Research.
- Yassen, A. A., Adam, S. M., and Zaghoul, S. M. (2011). Impact of Nitrogen Fertilizer and Foliar Spray of Selenium on Growth, Yield and Chemical Constituents of Potato plants. *Australian Journal of Basic and Applied Sciences*.2011; 5(11): 1296- 1303.
- Yuan, L., Wu, L., Yang, C., and Ly, Q. (2012). Effects of iron and zinc foliar applications on rice plants on their grain accumulation and grain nutritional quality. *Journal of Science, Food and Agriculture*. 2012; 93: 254-261.
- Zaidi, A., Khan, M. S., Amil, M. (2003). Interactive effect of rhizotrophic microorganisms on yield and nutrient uptake of chickpea (*Cicer arietinum* L.). *Eur J Agron*. 19:15–21.
- Zhou, T., Geller, M. A., and Lin, W. (2012). An observational study on the latitudes where wave forcing drives Brewer-Dobson upwelling. *J. Atmos. Sci.*, **69**, 1916-1935, doi:10.1175/JAS-D-11-0197.1.
- Zingore, S., Delve, R. J., Nyamangara, J., Giller, K. E. (2007). Multiple benefits of manure: the key to maintenance of soil fertility and restoration of depleted sandy soils on African smallholder farms. *Nutr. Cycl. Agroecosyst*. 80, 267–282.

APPENDICES

Appendix 1: Amount and cost of fertilizers used in the field experiment

Nutrient	Product	Nutrient content	Rate to applied (Kg/ha)	Total product to applied (kg/ha)	Total bags/ha	Unit price/bag (ghc)	Total amount (ghc)/ha	Total product to applied on 100m ² in grams	Total product to applied on 25 m ² in grams
Nitogen	urea	46%N	90	196	3.9	110	429	1960 split 1/3 and 2/3	490 split 2/3 and 1/3
Phosphorus	Triple superphosphate	48%P ₂ O ₅	60	130	2.6	130	338	1300	325
Potassium	Muriate of potash	60%K ₂ O	60	100	2	120	240	1000	250
Sulfur and magnesium	Kieserite	20%S and 25%Mgo	6kgS/ha and 7.5MgO/ha	30	0.6	85	51	300	75
Calcium	Nitrabor	25%CaO	10kgCao/ha	40	0.8	80	64	400	100
Boron	Etibor	15%B	1.5kgB/ha	10	0.18	200	36	100	25
Zinc	ZnSO ₄	36%Zn	2.5kgZn/ha	7	0.28	80	22.4	70	17.5
Copper and Molybdenum	Croplift	0.1%Cu and 0.003%Mo	Foliar application (2.5 kgCu/ ha and 2.5 kgMo/ ha)	2.5	2.5	23	57.5	25ml	6.25
Total				515.5			1237.9		

Appendix 2: Analysis of variance for the effect of the individual treatments on dry shoot weight

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	130.0309	7	18.57585	10.81957	6.45E-07	2.312741
Within Groups	54.94	32	1.716875			
Total	184.9709	39				

Appendix 3: Analysis of variance for the effect of the individual treatments on grain weight

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	63182432	4	15795608	5.524848	0.006141	3.055568
Within Groups	42885183	15	2859012			
Total	1.06E+08	19				

Appendix 4: Analysis of variance for the effect of the individual treatments on agronomic efficiency

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	344.0999	3	114.7	1.44389	0.278876	3.490295
Within Groups	953.2582	12	79.43818			
Total	1297.358	15				

Appendix 5: Analysis of variance for the effect of the individual treatments on economic viability

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	40.73062	3	13.57687	0.92502	0.458338	3.490295
Within Groups	176.1286	12	14.67738			
Total	216.8592	15				