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. Because 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 experimentin a randomized complete block design (RCBD) with four replicates.The test crop was Lake 601 maize variety. Data for the research was collected on; thetotal number of plants, stalkweight, Hurst weight, cob weight, grain weight Nutrient Use Efficiency, and Economic Viability. The data were 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 to 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, andanimal 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 tothehuman diet (Enyisi *et al*., 2014). Maize is grown extensively in temperate, sub-tropical, and tropical regions of the world. World total maize production is 1.04 billion tonnes from which theUSA 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 are 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 anincreased 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 thesoil 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). To achieve optimum productivity of maize crops, 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 theapplication of various nutrient elements such as nitrogen (N), phosphorus (P), potassium (K), sulfur (S), and some trace elements 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 theplant, essential for cell division, important for seed and fruit formation, affect the quality of the grains, and may increase the plant's 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 thedry 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). The 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 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 thestabilization 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 theregulation and maintenance of 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).

Sulfur 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 thephysical condition of the soil (Choudhary and Das, 1996). The increasing level of S progressively enhanced the average total N uptake by maize and this increase in N uptake may be attributed to anincrease in N content of plant and dry matter 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 amounts namely 10 to 30 kg ha^{-1}. The synergistic effect of applied P and S was observed by Kumawat (2004). An antagonistic relationship between P and S was observed in mung and wheat (Islam *et al*., 2006) and maize (Muhammad *et al*., 2015). This interaction influences the absorption of sulfur, in form of sulfate 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 – thesum 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 aseasonal 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, thedemand 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. Because 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 theapplication of primary, secondary, and micro nutrients improve nutrient use efficiency in maize?
ii. Does theapplication of primary, secondary, and micronutrients improve thegrain yield of maize?
iii. Does theadditional 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 ofthem hasashort life cycle and requires warm weather. Maize generally is a tall, monoecious annual grass with overlapping sheaths, andbroad distichous blades it is wind pollinated and both self and cross-pollination are possible (Hitchcock and Chase, 1971). Maize is cultivated across the globe and provides 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 inproduction could be attributed to its uses for food, feed, and industry. Maize has been identifiedas the world’s highest animal feed ingredient; It has high energy content, andlow fiber content andcan easily be digested by most livestock species (Plessis, 2003). Maize is primarily used as afeed grainin 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 thepopulation and provides 50 % of the basic calories. It is a vital source of carbohydrates, 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, andbaked and plays a crucial role in solving hunger problems after the dry season. All parts of thecrop can be served as food and non-food products. Maize grains serve a great nutritional valueas they contain 10 % protein, 4.8 % oil, 8.5 % fiber, 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 metrictons in 2010 to 118,100 metric tons by 2015 (MiDA, 2006). In thedeveloping world, it is consumed directly and also serves as astaple food for some 200 millionpeople, especially in Latin America and Africa (ITTA, 2009). Fresh maize can be boiled orroasted and eaten or when dry the grains are milled in dry or wet states into floor or dough forvarious 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 fabricmanufacturing and as adhesives (Buah *et al.*, 2009**).** It can also be processed asfuel (ethanol). The starch changes into sorbitol, dextrin, sorbic, and lactic acid, and appears inhousehold 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 beprocessed into secondary products such as corn flacks and popcorn.Maize production, processing, and sales both locally and as anexport commodity are major meansof 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 thegrowing 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 ºC and above. Temperatures below 8 ºC or above 40 ºC 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 a40 % 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 their total water requirement after tasseling and inadequate soil moisture at thegrain filling stage results in a poor yield and shriveled grains. A prolonged cloudy period is harmful to the crop but intermittent sunlight and cloud of rain are the most ideal for its growth. It needs bright sunny days for its accelerated photosynthetic activity and rapidgrowth (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 conditions, 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 thedevelopmental stage, and past studies have shown that themaize 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 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, themaize 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 moving them down the silk to the ovule where fertilization occurs (Nielsen, 2013). At thekernel blister stage (R2), kernels are very small and white. 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. The 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). TheDent 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

The 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). The grain yield of themaize 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 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 thepotential kernel number per row. Conversely, excellent growing conditions can encourage unusually high potential kernel numbers (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 thekernel 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 are 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 theeffective 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 include higher photosynthetic rate, leaf area duration, larger sink size, high leaf angle, and decreased anthesis-silking interval (Borras and Westgate, 2006).

2.6Effect 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 (othersbeing P and K). It has many functions including promotion of rapid growth, increasingleaf sizes and quality, and enhancing fruit and seed development; forms an integralcomponent of many important components in plants including amino acids that arebuilding blocks of proteins and enzymes, that are involved in catalyzing mostbiochemical 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 to determining maize sink capacity and helps to maintain functional kernels throughout grain filling. Asdetermined by its functions N influences the rate of crop growth and crop quality. Itincreases the plumpness of the cereal grains, the protein content of both seeds andfoliage, and the succulence of crops such as lettuce and radish (Foth and Ellis, 1988).Oversupplying of N especially with higher NH4 –N: NO3-N ratios, is reported to reducecalcium uptake (Bar-Tal*et al.*, 2001). On the other hand, calcium is needed for thesynthesis of strong cellwalls (Capdevillea*et al.*, 2005). A quadratic relationship in Ca uptake with anincrease in N amount appliedwas reported from a study on N nutrition in pepper (*Piper nigrum* L.) in Israel in whicha decrease of 50% for Ca uptake was noted from the peak (at 7.0 mmol L-1 N) to thehighest application of 15 mmol L-1 N (Bar-Tal*et al.*, 2001). Increasing available N or N application hasalso been reported to reduce theoil 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, andleaf chlorophyll status, especially as leaves age and vegetative biomass. Such aphenomenon decreases 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 (aprotein that improves bread-making quality)	Fuertes-Mendizábal *et al.*, 2012
Maize	Kernel weight, grain protein, and seed starch	Campillo *et al.*, 2010; Kling *et al.*, 1998
Sweet potato	Crude protein	Phillips *et al.*, 2005
Potato	Protein content, starch, and total carbohydrate content	Yassen *et al.*, 2011
Rice	Protein content	Sidkar *et al.*, 2008
Mandarin orange	Fruit size and weight	Hammami *et al.*, 2010

2.6.1.2 Phosphorus

Phosphorus is a very important macronutrient involved in most growth processes. It isan essential component of most organic compounds in the plant including nucleic acids,proteins, phospholipids, sugar phosphates, enzymes, and energy-rich phosphatecompounds, a common example being adenosine triphosphate (ATP) (Sylvia *et al.*, 2005; Brady andWeil, 2008). Researchhas determined that P improves crop quality in several ways including reducedgrain moisture content, winter hardiness, increased sugar content, increased proteincontent, increased P content, anincreasing proportion of marketable yields, better feedvalue, 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} applicationcompared with a control (without P application) was reported in a study done inNorthern Guinea Savanna of Nigeria (Magani and Kuchinda, 2009).As noted under thenitrogen discussion, most nutrients produce the best effects underbalanced nutrition. A 25% maximum protein content was reported from a plot fertilizedat 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). The synergistic effect isone of the factors that increases crop quality as far as N and P applications are concerned.Application of 40 Kg P ha^{-1} increased N and K accumulation in the maize grain by22.5% 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 anyother nutrient except N (Roy*et al.*, 2006). Unlike N, P, and most other nutrients, K is not incorporatedinto thestructures of organic compounds; instead, potassium remains in ionic form (K+) insolution in the cell and acts as an activator of many cellular enzymes (Havlin*et al.*, 2005). Therefore, ithas many functions in plant nutrition and growth that influence both theyield and qualityof the crop. These include regulation of metabolic processes such as photosynthesis;activation of enzymes that metabolize carbohydrates for thesynthesis of amino acids andproteins; facilitation of cell division and growth by helping to move starches and sugarsbetween plant parts. It is reported that among the many plant mineral nutrientspotassium (K) stands out as a cation having the strongest influence on quality attributesthat determine fruit marketability, consumer preference, and the concentration ofcriticallyimportant human-health associated phytonutrients or bioactive compounds(ascorbic acid and Beta carotene) (Jifon and Lester, 2009; Lester *et al.*, 2010). Some examples where fruit qualityincreased due to K application are presented in Table 2.All the increase in quality as described in this section can be attributed to the involvementof K in thesynthesis and movement of different products to their sinks (Havlin*et al.*, 2005). A condensedreview 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*et al.*, 2010
Banana	Bunch weight; decreasing acidity; increasing shelf	Mitra, 2009
Tomato	Increased carotenoids and flavor	Mikkelsen, 2005
Pawpaw	Sugar content	Lester *et al.*, 2010

2.6.1.4 Sulphur

Sulfur is the most abundant element in the earth's crust (Havlin*et al.*, 2005). It is absorbed by plantsas Sulphates (SO4^{2-}). It is responsible for the formation of thedisulfide bond between cysteine residues that help to stabilize the tertiary structure ofproteins (Sylvia *et al.*, 2005). It is also needed in the synthesis of coenzyme A and chlorophyll. Thedeficiency of S leads to theaccumulation of non-protein N such as NO3$^-$ and amine (NH2) (Havlin*et al.*, 2005). Sulfur deficiency has been reported to lead to theaccumulation of NO3$^-$ in vegetableswhich are dangerous as these lead to fatal conditions such as methemoglobinemia ininfants and theformation of cancer-inducing nitrosamines (Sylvia *et al.*, 2005). Increased rice grain quality(N content) by S containing nitrogenous fertilizers, supernet (1.73% N), and ammoniumsulfate nitrate (1.66% N) as compared to urea that produced 1.45% N was reported inIndia (Chaturvedi, 2005). This could be attributed to the role of S in protein synthesis in which it is usedas an essential component of amino acids and also the balanced fertilization that leadsto the general high performance of the crop including synthesis of all N-containingcompounds such as proteins, chlorophyll, and nucleic acids.An increase in glucosinolates, sulfur-rich metabolites of the order Brassicales in therange of 25% to more than 50% with sulfur fertilization was also reported (Falk*et al.*, 2007).Sulfurapplication has been reported to increase the quality characteristic such as the pungentsmell of 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 majorcomponent of the middle lamella (Ca-pectates) of the cell wall. It strengthens the cellwalls and is involved in cell elongation and division, membrane permeability, andactivation of several critical enzymes (Brady and Weil, 2008). It is important in N metabolism and proteinformation by enhancing NO3$^-$ uptake and it is also important in thetranslocation ofcarbohydrates and other nutrients (Havlin*et al.*, 2005). Following its functions, calciuminfluences crop and food quality. Calcium is less mobile such that its influence on cropquality is easily noted with foliar application. Seven-fold calcium foliar application alsoimproved some fruit quality characteristics of 'Sinap orlovskij' apple such as fruitcalcium content (high quality) increased by 50 – 150mg/kg and decreased bitter pitincidence (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 primaryconstituent of chlorophyll and as a structural component of ribosomes, it helps in theirconfiguration for protein synthesis (Havlin*et al.*, 2005). It is also required for maximum activity ofalmost all phosphorylating enzymes in carbohydrate metabolism. Adequate levels ofMg in the USA reported increased quality and profits of potatoes due to improved potato-specific gravity (Hoyum, 2000). The increased specific gravity of potatoes can be attributed toincreased carbohydrate synthesis and deposition from the leaves. Usually, the firstthings to be noticed due to theinfluence of Mg are chlorophyll level, photosynthesis(photosynthetic CO2 fixation), and protein synthesis, however, recently, thedistribution ofcarbohydrates among shoot and root organs has been reported as well (Cakmak and Yazici, 2010). These inturn affect thequality of plant products depending on which part is used for food by humansor animals. A four-fold increase of sucrose in leaves of Mg-deficient sugar beetscompared to the Mg-adequate sugar beet plants was reported and this affected qualityof Mg-deficient sugar beets (Hermans *et al.*, 2004). This was attributed to theinhibition of sucrose/sugardistribution 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 beessential for plant growth. Others such as selenium (Se) and Co, which are needed inspecific cases are commonly referred to as beneficial elements. For instance, Co isrequired by bacteria that fix nitrogen in legumes. Zinc (Zn) and iron (Fe) are some ofthe most important micronutrients essential for plant growth (Muthukumararaja andSriramachandrasekharan*et al.*, 2012; Kumar*et al.*, 2012). Zinc is a majormetal component and activator of several enzymes involved in metabolic activities andbiochemical pathways (Kabata-Pendias and Pendias, 2011; Grotz and Guerinot, 2002). It is a functional, structural or regulatory co-factor of alarge number of enzymes (Grotz and Guerinot, 2002). It is required in a large number of enzymes and plays anessential role in DNA transcription (Kumar*et al.*, 2012). Other functions of zinc include: catalyzing theprocess of oxidation in plant cellswhich is vital for the transformation of carbohydrates;and influencing the formation of chlorophyll and auxins, the growth-promotingcompounds (Mamatha, 2007).On the other hand, Fe in a constituent of the enzyme system which bringsabout oxidation-reduction reactions in the plant, it regulates respiration, photosynthesis,andreduction of nitrates and sulfates (Mamatha, 2007). These reactions are essential to plantdevelopment and reproduction. It should be noted that as in the case with other plant micronutrients Zn and Fe limit plant growth when they are present both in lowconcentrations and in excessive concentrations due to deficiency and toxicityrespectively (Conolly and Guerinot, 2002; Alloway, 2008).

Table 3: Crop quality characteristics improvements by some micronutrient applications in various crops

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

	content; grain Zn and Fe content		
Pomegranate	Fruit weight; fruit diameter	Zn; Fe	Hasani *et al.*, 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's physical and chemical properties, thereby, increasing plant nutrient concentration and nutrient uptake (Mugwe *et al.*, 2007). Manure application also enhances soil moisture retention capacity, regularizes soil pH, and supplies 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 are immediately available for plant uptake and use; thus, it is required to supply thesoil 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. A combination of chemical fertilizers with organic materials such as cattle manure is a recommended strategy to enhance theefficient 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 affects plant growth. Animal manure nutrients are, however, released slowly during the cropping season due to its high C/N ratio (Mugwe *et al.*, 2007).

To meet themaize crop's nutrient demand, thesupply 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 in 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 themost efficient use of animal manures depends critically on improving thesynchrony 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 before 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 be attributed to the additive nutrient supply and bettersynchrony of nutrient availability with crop demand, i.e., the immediate availability ofnutrients 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 andsenescence dynamics in maize (*Zea mays* L.), and itsdeficiency slows down the rate of leaf appearance andreduces the final leaf area located below the main ear by18 to 27% (Colomb *et al*., 2000). In K-deficient soil,crop yield is reduced and N and P responses will be small(Balasubramaniyan and Palaniappan, 2001). Potassium,a primary macro nutrient, helps in the translocation ofmanufactured food andhas a stimulating effect on growthand development, and grain yield in maize(Davis *et al*., 1996). Its application has anascent 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 the 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. The temperature in the municipality is generally high, averaging about 24.5 °C. The 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, P_2O_5, K_2O, 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, plowed, and weeded before plots were marked and demarcated. The plots of 5× 5 m^2 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 replicated 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 cmat 75 x 50 cm spacing. Weeding was done manually with ahoe to keep the fields free from weeds. In all fertilizer applications, point placement was used in other 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 phosphorus (60 kg P_2O_5/ha) and potassium (60 kg K_2O/ha) were applied as Triple superphosphate and Muriate of potash respectively 2 weeks after planting. Manure (cow dung) was applied at 6000 kg/ha. Zinc (Zn) was applied as Zinc sulfate ($ZnSO_4$) at 2.5 kg Zn/ha. Sulfur (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 Nitrabor at 10 KgCaO/ha. Boron was also applied in the form of Nitibor 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. ***The total number of plants:***The total number of plants on each plot (per treatment) was 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. Afterward, 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 %. Afterward, the seeds are weighed per plot and recorded.

vi. ***Agronomic efficiency:***This will be determined 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 = ΔY (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 were analyzed with analysis of variance (ANOVA) on all measured parameters. Means for each parameter were separated by the least significant difference (LSD) method at a 5 % level of significance.

RESULTS

4.1Dry shoot weight

There was a highly significant difference ($P < 0.05$) among the individual treatments concerning 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.

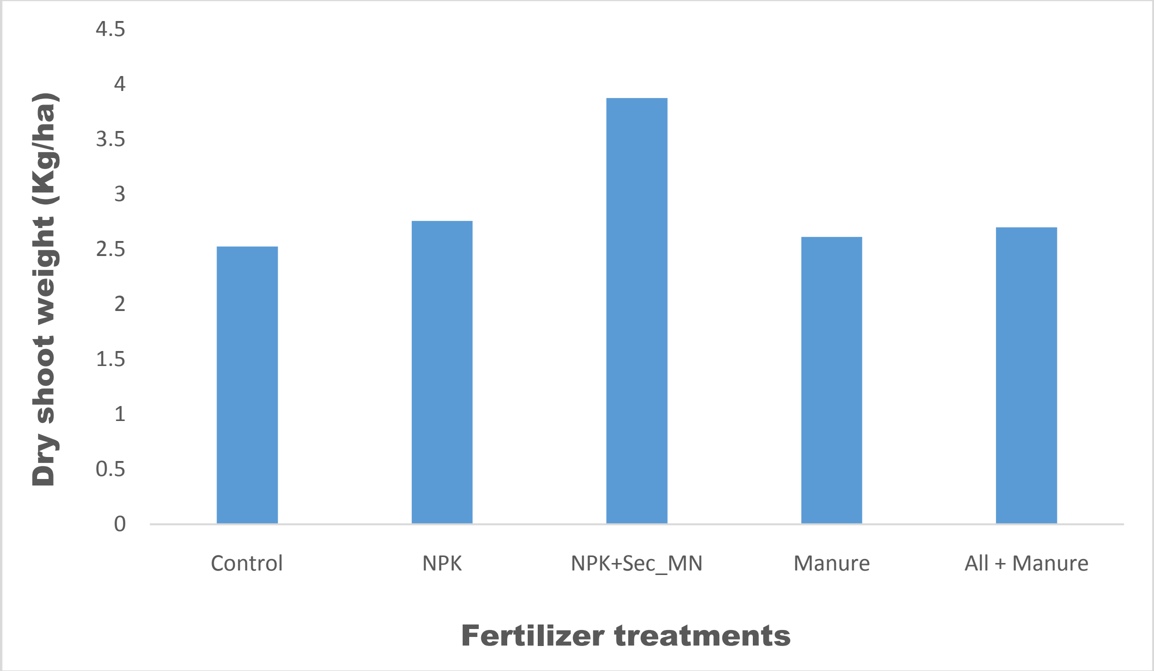

Figure 1: Effect of the treatments on dry shoot weight

4.2 Grain weight

Concerning 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 (Figure2).

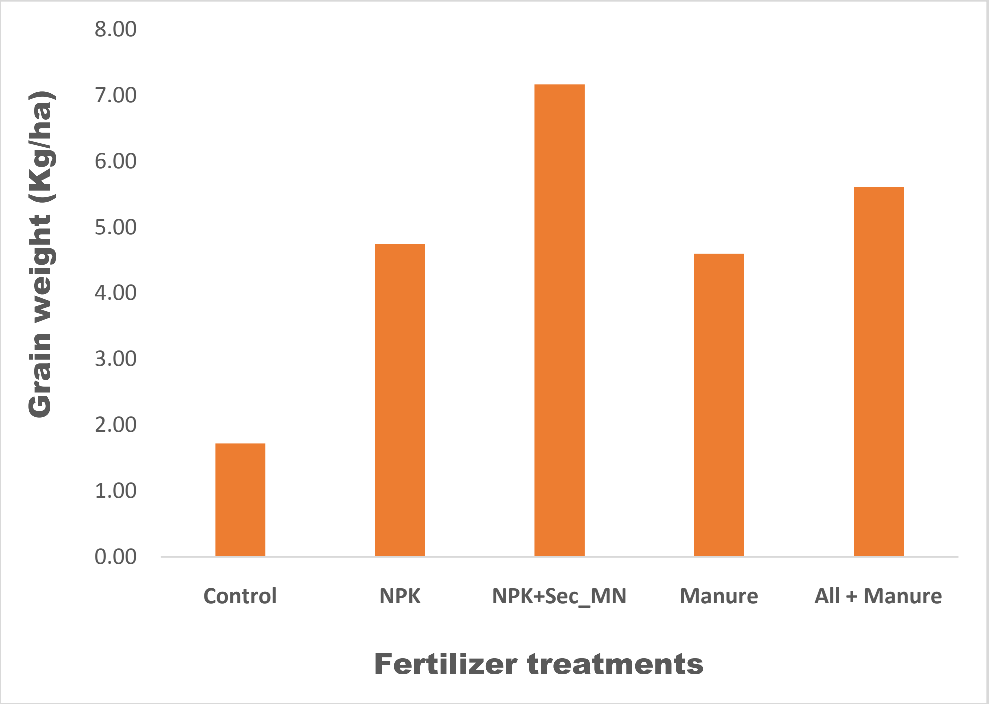

Figure 2: Effect of the treatments on grain weight

4.3Agronomic 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 tests for T1, T2, T3, T4, and T5were1722, 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 concerningtheir 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 every1kg of NPK and secondary nutrients applied, 24.5 ± 12.47 kgof maize was realized. These results imply that it ismore 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**				
	Rep 1	**Rep 2**	**Rep 3**	**Rep 4**	**Mean (kg)**
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

4.4Economic Viability (EV)

Economic viability (EV) is an important index used to evaluate the likely profitability of 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 profitabilityof using the other treatments (T2, T3, T4, and T5).The results revealed thatthere was no significant difference ($P > 0.05$) among the individual treatments concerning their economic viability (EV). However, T3 (NPK + Sec_nutrients) proved to be more economically feasible (GH¢ 9.2 ± 4.7). These results imply 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 compared 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**				
	Rep 1	**Rep 2**	**Rep 3**	**Rep 4**	**Mean (GH¢)**
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 performancesconcerning its effect onstalk 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), sulfur (S), and some trace (secondary) elements to boost crop productivity (Ayodele and Omotosho, 2008; Adekayode and Ogunkoya, 2010).The use of micronutrients increased the yield and also the uptake of nutrients when applied in combination with macronutrients as compared to conventional fertilization which lacks 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 the regulation and maintenance of 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 to the importance of S in plant growth. This statement is further supported by Choudhary and Das, (1996) who reported that Sprovides beneficial effects by lowering soil pH and improving the 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 the grain yield of maize. Zinc (Zn) is also considered an important secondary nutrient essential for plant growth (Kumar*et al.*, 2012). According to Brown *et al*., (1993),the formation of male and female reproductive organs and the 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 cells and is vital for the transformation of carbohydrates; and influencing the formation of chlorophyll and auxins, the growth-promoting compounds (Mamatha, 2007).

5.2Assessment 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 sustainable food crop production have made the need for information on 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 takes place in plants during thegrowth 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 on 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 the 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 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 in 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 combined 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 the 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 to 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 the 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.

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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 100m2 in grams	Total product to applied on 25 m2 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%P2O5	60	130	2.6	130	338	1300	325
Potassium	Muriate of potash	60%K2O	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	ZnSO4	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

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
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

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
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

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
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

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