EVALUATION OF NEWLY RELEASED MAIZE VARIETIES IN GHANA FOR YIELD AND STABILITY UNDER THREE NITROGEN APPLICATION RATES IN TWO AGRO-ECOLOGICAL ZONES

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AUGUST, 2012

DECLARATION

I hereby declare that, except for specific references which I have duly acknowledged, this work is the outcome of my own research and that neither a part nor whole of this document has been submitted for any other degree at any other University.

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We declare that we have supervised the above student to undertake the study submitted herein and verify that she has our permission to submit.

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To Prof. Richard Akromah, for his immense support.

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ABSTRACT

Farmers' adoption of hybrid varieties would reduce the large discrepancy between current low yields and achievable yields reported by maize researchers in yield evaluation trials as hybrids wield superior genetic potential over improved open pollinated varieties (OPVs) and local varieties due their heterozygosity resulting in their exhibition of high heterosis in yield and general performance. The current low yield necessitated the need to undertake this study to assess the relative yielding abilities and stability of 3 hybrid varieties, 5 OPVs, 1 local variety and 4 inbred lines under three levels of nitrogen fertilization at Kwadaso, a forest ecology, and Ejura, a transitional ecology, both in the Ashanti region of Ghana, in the major and minor seasons of 2011, respectively. Analysis of variance (ANOVA) revealed significant interactions for genotype by location (G x L), genotype by nitrogen (G x N) and genotype by nitrogen by location (G x N x L) for grain yield. GGE biplot analysis for mean yield and stability also showed that hybrids had better yielding abilities than OPVs under both low and high nitrogen fertilization and at different environment. Economic benefit analysis also revealed that best option for highest net benefit is the cultivation of hybrid varieties under 90 kg N ha^{-1}. In order to bridge the gap between the current low yields and achievable yields in Ghana, farmers need hybrid seeds together with adequate levels of fertilizers.

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CHAPTER 1

1.0 INTRODUCTION

Maize (*Zea mays* L.) is a major cereal crop in West Africa, accounting for slightly over 20% of the domestic production in the sub-region (IITA, 2000). It is one of the most important cereals in Ghana, which is cultivated in all the agro-ecological zones (Fening *et al*., 2011).

Maize yield averaged 4.9 t ha^{-1} globally in 2009 (Edgerton, 2009). However, yields in major maize growing areas in the developing world still lag behind the world average, producing only about 3.1 t ha^{-1} (Pixley *et al*., 2009). Yields in the United States for example have increased remarkably from an average of 1.6 t ha^{-1} in the early 1930's to the current approximated yield of 9.5 t ha^{-1}, whereas yields presently obtainable in Ghana hover around 1.7 t ha^{-1} (Edgerton, 2009; MoFA, 2011). This large discrepancy in yields has been ascribed partly to the use of unimproved or open pollinated varieties (OPVs) instead of hybrids, low input rates and poor soil management (Edgerton, 2009). MoFA (2011) reported that achievable yields of about 6 t ha^{-1} have been obtained in maize yield evaluation trials. This therefore indicates that the average maize yield of 1.7 t ha^{-1} currently obtained in Ghana, is about 70% less than what is usually achieved in maize yield trials by researchers. Attempts have therefore been made to bridge the gap between the current low yields and the achievable yields by promoting the use of hybrid maize varieties. Breeding programmes in Ghana over the last two decades, among other activities, have been geared towards the development of hybrid varieties due to the superior genetic potentials they wield over their open-pollinated counterparts. This is in agreement with the current drive in maize production worldwide which is to encourage a shift from the use of OPVs to hybrid cultivars to take advantage of hybrids that recorded high heterosis in yield and general performance (Karunaratne, 2001). The cultivation of hybrid maize varieties has contributed to remarkable yield increases in many maize growing countries in the world (Karunaratne, 2001).

Farmers however have provided a range of reasons why they may not invest in hybrid seeds, some of which are high hybrid seed prices, non-availability of hybrid seed at local shops, high requirement of fertilizer for cultivation, small or no differences in yield when compared to local varieties, poor storability and poor processing quality (Pixley and Banziger, 2001). These arguments have raised the question whether hybrids have indeed an advantage over open pollinated or local varieties under resource- poor farmer conditions where insecure seed availability, low input use and crop failures due to erratic rainfall are common.

In addition to the genotype, a crop's phenotype is equally influenced by the environment, as well as genotype (G) by environment (E) interaction (or G x E interaction), which accounts for a significant portion of yields attainable in improved varieties (Sallah *et al.*, 2004). High G x E interaction influence on yield due to location, seasons, soil fertility levels and sowing dates have been reported in Ghana (Ewool, 2004). Yield stability of maize genotype is influenced by the capacity of the genotype to react to environmental conditions, which is determined by the composition of the genotype (Borojevic, 1990). Hence extensive studies of maize varieties under stress and optimal growing environments would be useful for identifying varieties that combine high yielding abilities with stability.

Soil fertility decline is also a major biophysical factor challenging crop production in Ghana (Logah *et al*., 2010). Current increasing population however has put pressure on agricultural lands, preventing resource poor farmers from engaging in shifting cultivation and bush fallowing which initially was the best option for sustaining soil fertility and crop production. This has resulted in declining soil fertility and consequent reduction in yield (Alabi *et al*., 2003). In developed countries, nitrogen deficiency is alleviated by the addition of inorganic fertilizer. This however is impossible in developing countries because, either fertilizers are unavailable or are very expensive for small scale subsistent farmers (Mkhabela and Pali- Shikhulu, 2001).

Maize breeding programmes in Ghana has seen transformation from the initial dedication to the development of Quality Protein Maize (QPM) OPVs to the current era of hybrid variety promotion. According to IITA report in 2000, 31 varieties had been released between 1965 and 1998 alone. Ewool (2004) attributed 33% to 41% increases in yields in Ghana to breeding of improved hybrids over OPVs by 1997 under sufficient nitrogen supply. 49% to 63% genetic gain in yield was also attributed to the replacement of local varieties with hybrid varieties available within the same period. Eight new varieties have since been released after this research.

The present study therefore aimed at evaluating performances of some of the new varieties under three levels of nitrogen fertilization in two agro-ecological zones of Ghana.

The specific objectives were:

1. To assess the relative yielding abilities of maize genotypes under different levels of N fertilization.

2. To assess stability of genotypes across the environments used
3. To estimate genetic correlations between yield and other traits of agronomic importance.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 History of maize breeding in Ghana

With organized maize breeding in Ghana seemingly commencing in the early 1930's after the crop was introduced by the Portuguese in the 16th century, the focus or mandate of maize breeders in Ghana has mainly been to develop high and stable yielding maize varieties that will perform well in all the agro-ecologies in Ghana (GGDP, 1986). Between 1939- 1942, T.L Williams developed few local maize germplasm, introduced a yellow variety called 'Tsolo' from South Africa and developed the C50 variety (GGDP, 1984; Sallah, 1986). Nyankariwana Number 1 and Number 2, both yellow varieties in Northern Ghana were also released by J. McEwen between 1954 and 1961. Within the period of 1956 – 1960, W.K Agble also supported maize breeding in Ghana by releasing Synthetic 1, 2, and 3 as (GS1, GS2 and GS3) from parental inbred lines (GGDP, 1984; Sallah, 1986). Effort by some local Ghanaian breeders, especially M. K. Akposoe led to the development of three composite varieties: composite1, 2 and 3, in addition to La Posta CRI, and Golden Crystal between 1968 and 1972. Other varieties such as Composite 4, Dobidi and Okomasa were also released between 1972 and 1988 (Sallah, 1998). Maize breeding efforts in Ghana intensified in 1979 with the beginning of the Ghana/CIDA Grains Development Project (Sallah, 1986). During the period of the project, the maize improvement programme developed and released white and yellow populations with various maturity periods ranging from 80 to 120 days to suit the different agro-ecological zones of Ghana. Majority of the recent germplasm used by breeders in improvement programs came from the International Maize and Wheat improvement Center (CIMMYT) in Mexico and

International Institute for Tropical Agriculture (IITA) in Nigeria. Variety “Okomasa”, a normal, full-season open pollinated maize variety (OPV) for example has its origin from CIMMYT Population 43-SR, was released in 1988 and has a yield potential of 5.5t ha^{-1} (Sallah, 1986). Such older varieties improved and released by CRI were open pollinated normal maize varieties. QPM breeding programme in Ghana was initiated in 1989 which led to the release of ‘Obatanpa’ in 1992 (Sallah, 1998). Between 2007 and 2010, extra early maturing QPM varieties such as ‘Akposoe’ and ‘Abontem’; early maturing varieties ‘Omankwa’ and ‘Aburohemaa’; and intermediate maturing varieties, ‘Etubi’, ‘Enibi’, ‘Golden Jubilee’ and ‘Aziga’ have been released (Variety release, 2007 & 2010). QPM hybrid development programme commencement in 1991 resulted in the development of some intermediate hybrids such as ‘Mamaba’, ‘Dadaba’ and ‘CIDA-ba’ in 1996 which had high yield potentials of 7.5 t ha^{-1} on experimental stations. Some recently released high-yielding hybrid varieties are ‘Etubi’ and ‘Enibi’ which were released in 2007 and 2010 respectively with improved drought tolerance.

2.2 Advantages of hybrid Maize over open pollinated maize (OPV)

Hybrids varieties are genotypes developed from cross of two or more inbred lines that exhibit superior qualities over their parental inbred lines due to their exploitation of hybrid vigor due to their heterozygosity and hence seeds cannot be saved for the next growing season (Prest, 2010). Open-pollinated varieties are those varieties produced by cycles of open-pollination followed by selection of the most desirable ears at harvest; through continued selection the varieties become adapted to the area being grown with every plant grown from saved seed being genetically unique (Prest, 2010).

Maize inbred lines on the other hand are breeding strain of maize that is produced after several generations of self pollination hence causing them to become homozygous at all loci hence the progeny are genetically identical to the parent (Prest, 2010).

Hybrid maize was first introduced in the USA in the late 1920's and early 1930s, and was well received by farmers and swiftly substituted open-pollinated maize varieties in the main maize growing areas of the country (Duvick, 1999). Shull (1909) was the first to report increased yield from F_1 crosses between open pollinated inbred lines. East and Hays (1912) attributed the vigor of those F_1 to their heterozygous condition, thus the greater the number of genes in which the plant or hybrid is heterozygous, the greater the heterosis (Jugrenheimer, 1976). The earliest maize hybrids yielded merely about 15% greater than the better open pollinated varieties (OPVs), nevertheless they, to a large extent had better resistance to root and stalk lodging (Ayinde *et al*., 2011). Some founders of hybrid maize have reported that the very first hybrids might not have been accepted so rapidly, if their superior yield had not also been accompanied by better resistance to lodging (Duvick, 1999). Uniform growth and ability to provide extra grains per each ear harvested, high plant vigour resulting from increased metabolic activities are the attributes for the growing interest in hybrid maize in farmers around the world (Karunaratne, 2001). In the past 40 years, total, maize production in China has increased by 623%. A survey revealed that in yield gain, hybrid maize varieties alone generated 22% and fertilizer application 24% (Karunaratne, 2001). In tropical areas, improved hybrids and OPVs also account for major share of yield increase (Pixley *et al*., 2009). In recent times, hybrid maize production has been given widespread support among farmers in developing countries although it is renowned for its high demand for plant nutrients as well as additional production inputs (Ayinde *et al*., 2011).

According to Pixley *et al.* (2009), the replacement of local varieties and landraces with improved OPVs have generally produced 100% grain yield increases globally whilst the substitution of OPVs with hybrid maize further expanded yields by 15- 20%. Even though it is grown extensively in many countries in the world, some farmers still believe that all inputs crucial for maximum production of hybrid maize must be met before realization of the best possible output. As a result, the extra cost of production discourages a good number of farmers from engaging in hybrid maize production in developing countries (Ayinde *et al*., 2011). Further studies added that the yield of hybrid maize, differ from species to species, place to place and besides, it relies on the availability of crucial factors such as soil nutrient status and application of fertilizer (Kogbe and Adediran, 2003).

The yield advantage hybrids have over OPVs sighted by Correjado and Magulama (2008) in the work of Paliwal (2000) indicated 46% for single cross, 30% for three way cross, 37% for double top cross, 28% for top cross, and 17% for variety cross concluded that hybrid yields are generally higher than improved OPVs. For example hybrid yields in the US Corn Belt are averaged at 7 tons ha^{-1} compared to the 3 to 4 tons ha^{-1} for OPVs in the same environment (Carlone and Russell, 1987). In a study conducted by Ayinde *et al*. (2011) to compare input-output relationship in hybrid and open-pollinated maize production in the US, an average yield of 2240.6 kg per hectare was obtained by hybrid maize farmers by using 16.12 kg of seed, 6.04 bags (i.e. 302 kg) of fertilizer and 65.12 man-hours. On the other hand, the open pollinated maize farmers realized an average yield per hectare of 1261.0 4 kg, through the use of 38.31 kg of seed, 2.23 bags (i.e., 111.5 kg) of fertilizer and

55.9 man-hours. The average quantity of insecticide and herbicide used in both hybrid and open pollinated maize production were 1.07lit and 0.79lit, 1.41lit and 1.36lit respectively (Ayinde *et al.*, 2011). Muza *et al*. (2002) also reported 27 to 28% yield advantage for hybrids over OPVs when they compared average yields of ten OPVs and five commercial hybrids at eight environments in Zimbabwe under two nitrogen levels. Further, when the yields of the best five OPVs were compared with the five commercial hybrids in the same study, yield advantage of hybrids were about 16% for unfertilized and 19% for fertilized plots. Pixley and Banziger (2001) reports 18% yield advantage of hybrids and speculated that a very good hybrid may out-yield a poor OPV by more than 70% even though a good OPV may be similar or even out-yield a poor performing hybrid.

Many new varieties possess genetic qualities that improve seed production in both favourable and unfavourable environments. For example the improved root strength in newer hybrid corn varieties has increased the plants ability to tolerate stalk-root fungi, heat, drought, limited nitrogen nutrition and pest (USDA, 2004).

2.3 Some advantages of landraces or local varieties

Although the first hybrid maize varieties were released in Sub- Saharan Africa more than 40 years ago, less than 30% of the total area planted to maize in the sub region today is planted to hybrid maize (Hassan *et al*., 2001). The remaining 70% is either planted to improved open pollinated varieties (OPVs) or local varieties (Morris, 2001). Numerous reasons have been assigned to this with the first being that, because considerable knowledge and capital are involved in hybrid seed production, it is generally only available where purchasing frequency and sales volume for hybrids are sufficient and thus guarantees profitability (Pixley and Banziger, 2001). It is therefore not surprising that sales of hybrid seeds have not been profitable in many African countries particularly in rural areas where purchasing power of farmers is low. Secondly and perhaps most importantly is the fact that farmers on the other hand have provided several reasons why they may not invest in hybrid seed. Their key concerns are high cost of seeds, lack of cash at planting time, non availability of hybrid seeds at local shops, the need to purchase fertilizer and small or no difference in yield when compared with local varieties, lack of adaptation, poor storability and poor processing qualities of available hybrids (Pixley and Banziger, 2001). These concerns have therefore raised the questions of whether hybrids have indeed an advantage over open pollinated varieties under resource-poor farmer conditions where insecure seed availability, low input use and crop failure is common.

Odendo *et al*. (2001) reported that nearly 80% of the farmers in Africa predominantly grow local maize varieties because they can recycle seeds for many seasons, whilst about 20% grow improved varieties, often in addition to the local varieties. The key farmers' criteria for variety selection, in order of importance, are high yield, early maturity, tolerance to stresses especially *Striga hermontica*, drought and insect pests, low costs of acquiring seed, and ability of a variety to give reasonable yield without application of external inputs, especially fertilizers and pesticides. Most farmers prefer local variety because they are perceived to be able to survive despite the odds of harsh environment, including *Striga hermontica,* low soil fertility and drought (Odendo *et al*., 2001).

Hybrid varieties are known for high yielding attributes, but have relatively poor performance in storability, flour-to-grain ratio, and taste. Local varieties are preferred by farmers for their ease of storage, high poundability, high flour-to-grain ratio and good taste (Odendo *et al*., 2001).

Some hybrid varieties are grown in both long and short rainy seasons, whilst others are only planted in either of the seasons. Farmers prefer local varieties because they can be grown in both seasons since they are drought tolerant and serve as a risk management strategy since the short rainy season is generally unreliable (Odendo *et al*., 2001).

Heavy and tight husks covering of local varieties is also an attribute of great importance to farmers because it minimizes attack by pests such as birds and stem borers (Odendo *et al*., 2001).

2.4 Maize growth environment

Environment is all microclimatological and physical factors such as water, temperature, soil conditions and all other factors that affect plant growth, development and yield (Beets, 1982). Maize yields vary depending upon variety, location, soil nutrient status and application of fertilizers. Nitrogen is a vital plant nutrient and a major yield-determining factor required for maize production (Adediran and Banjoko, 1995; Shanti *et al*., 1997). It is the most important element for plant growth and development. It is an integral component of many compounds essential for plant growth processes including chlorophyll and many enzymes. It also mediates the utilization of potassium, phosphorus and other elements in plants (Brady, 1984). Its availability in sufficient quantity throughout growing season is essential for optimum maize growth. Most farmers in developing countries usually rely on the natural soil fertility for crop production, however, subsequent cropping requires additional fertilizer input, most importantly that of nitrogen to maintain good yields. Phosphorus (P) is another limiting nutrient in maize production. Various factors could be responsible for P availability to crop plants. These include the form of native soil P, the type of P applied to the soil, and soil reaction. It has been reported that total P was higher in forest soils than in the savanna (Adepetu, 1970; Adepetu and Corey, 1975). The results of various fertilizer experiments carried out in developing countries have led to fertilizer recommendations that gave blanket nutrient requirements for maize in ecologies having varying soil conditions and under varying levels of soil management (FPDD, 1990). For example, hybrid maize cultivation was found to require high fertilizer rate for optimum yield. Findings from research work conducted by Sobulo (1980) indicated, that maize responded to nitrogen better in the savanna than in the forest ecology. It was further suggested, that 60-70 kg N ha^{-1} served as economic rate for maize in the rainforest, and over 100 kg N ha-^{1} in the savanna. The difference between the two zones was, however, attributed to the presence of higher insulation in the savanna zones (Sobulo, 1980). Some work earlier carried out with phosphorus fertilizer indicated positive response of maize to low rates of P (Amon, 1965; Amon and Adetunji, 1970). Application of high rate was reported to be capable of causing nutrient imbalance and consequently yield depression of western yellow maize (Osiname, 1979).

Nitrogen deficiency and excess can result in reduced yield in maize and its requirement can go up to 150 to 200 kg N per ha (Mkhabela and Pali- Shikhulu, 2001). Nitrogen is one factor that may limit crop yields (Edgerton, 2009). Nitrogen use efficiency (NUE) is defined as the amount of crop produced per unit of output and has steadily improved in the US since the 1980s and is believed to be under multiple gene control (Mi *et al.*, 2004). More precise nitrogen application and genetic improvements in crops is likely to sustain improvement in nitrogen use efficiency although there is a limit on how far nitrogen application can be reduced. Yield increase in maize is largely due to larger nitrogen fertilizer inputs (Mi *et al.*, 2008). Ear and grain development is severely inhibited by N deficiency (Below, 1996). It was found that yield reduction at low N stress is largely due to increased kernel abortion and fewer kernels per ear (Below, 2002). From an agronomic perspective, N-use efficiency (NUE) of a genotype refers to its grain yield at available N supply from both the soil and fertilizers (Moll *et al*., 1982). NUE therefore tends to increase with decreasing N fertilizer input. An N-efficient cultivar may produce a higher yield at low N and or at high N applications compared to the inefficient cultivars. In general, however, a cultivar which attains higher yields at relatively low N inputs is referred to as an N-efficient genotype (Moll *et al*., 1982).

In general, a genotype x N rate interaction cannot be observed when a large number of hybrids are compared (Below, 2002; Mi *et al*., 2004). Modern cultivars are therefore more N efficient because the physiological traits related to yield formation and resistance is comprehensively improved in modern cultivars. As a result, the traits related to N-use efficiency have been simultaneously modified (Mi *et al*., 2008).

Nitrogen-use efficiency of a cultivar is roughly determined by two factors. One is the efficiency of a plant in recovery of N from the soil, namely N-uptake efficiency and the other is the efficiency of a plant in the utilization of N to produce grain yield, namely N-utilization efficiency, or physiological N-use efficiency. Grain yield is ultimately limited by N uptake (Moll *et al*., 1982).

Numerous studies suggest that NUE and its related physiological traits such as N accumulation and re-translocation are mainly controlled by additive gene effects (Below, 1996; Chen *et al*., 2003). Direct selection for yield under low N supply is still the main method in breeding programs for N-efficient hybrids. Presterl *et al*. (2002) developed hybrids under low and high N conditions. They showed that the average yields of the hybrids developed at low N conditions were 11.5% higher at low N supply than those selected under high N conditions. There was no significant difference in yield between two hybrid types at high N supply. In addition, the N-efficient hybrids showed significantly higher N uptake at low N levels than the hybrids selected under high N. No differences in N-utilization efficiency were observed. Similar results were obtained in research by Chen *et al*. (2005). It may therefore be possible to increase maize yields at reduced N supply while maintaining the yield potential under high N inputs. This should be achieved by increasing total N accumulation under conditions of low N supply.

It has been a major challenge to increase crop yields while reducing N fertilizer inputs. Although modern breeding programs have aimed to increase maize yields at high N inputs, the ability to take up more N by modern hybrids under low N supply has been improved simultaneously. Nevertheless, there is still scope to increase the NUE of maize at low N supply by exploring the genetic resources (Mi *et al*., 2008).

Ewool (2004) reported that nitrogen fertilizer levels are significant for grain yield, days to mid silk, days to mid anthesis, anthesis silking interval, plant height, ear height, open tip, cob aspects, dry stover weight, cob length and grain depth at nitrogen levels of 0, 45 and 90 kg N ha^{-1}.

Castleberry *et al*. (1984) also reported that, when several hybrid time-series were grown at lower and higher levels of nitrogen fertilizer, in each case the newer the hybrid the greater the yield, at all levels of fertilizer application. Similar results were reported by Duvick (2005). The yield advantage of newer hybrids (compared with older ones) at lower levels of nitrogen fertilizer application indicates that nitrogen use efficiency has improved over the decades.

Ewool (2004) reported 41% and 33% yield advantage of planting QPM hybrids over the OPVs at 45 kg N ha^{-1} and 90 kg N ha^{-1} respectively and 49 to 63% yield increase by replacing the local varieties with the QPM depending on the nitrogen fertilizer rate (45 or 90 kg N ha^{-1}).

Kogbe and Adediran (2003) reported that hybrids efficiently utilize nitrogen better than open pollinated varieties. They further reported in the same study that hybrid yield increases with increasing nitrogen application up to 100 kg N ha^{-1} when a decline in yield is observed. This they reported erases the fear that without high nitrogen inputs, hybrids will not give appreciable returns. Again it was observed that hybrids have gradual decline or almost similar values of NUE at increased nitrogen rates and application of additional nitrogen led to reduction or almost similar units of weight of maize grains.

O'Neill *et al*. (2004) found that newer corn hybrids exhibited greater grain yield response to applied fertilizer N and greater N fertilizer use efficiency compared to older (1970s) hybrids. Yields under N deficient conditions varied among individual hybrids and these yield differences were not related to the age of the hybrid. Their study included only two N rates (0 and 224 lb/acre) gave yield differences, thus more detailed analysis regarding variability of the economic optimum N rate between hybrid eras could not be determined. They concluded that conditions which promote high corn yields, such as adequate moisture and temperature, improved the efficiency of available N use by the crop and greater amounts of applied N are not needed. Hence whether the greater yield potential associated with newer hybrids has a similar effect on N use efficiency and optimum N rates is unknown. Many agronomists believe higher N rates are needed to achieve the greater yield potential associated with these hybrids. However, larger root systems of hybrids could result in greater N use efficiency and perhaps a reduced N fertilizer need compared to OPVs (O'Neill *et al*., 2004). Since the work of Ewool (2004) in which he compared hybrids QPMs with OPVs, new drought tolerant hybrids have been developed in Ghana. These need to be evaluated for their N use efficiency, to assess benefits in using such hybrids by farmers rather than OPVs.

2.5 Genotype x Environment interaction

Genotype by environment interaction occurs when differences between genotypes are not the same in all locations within and across years. It is the inconsistency of relative performance of genotypes over environments (Edmeades *et al*., 2003). According to Sallah *et al*., (2004), the relative performance of genotypes often changes from one environment to another and this differential response of genotype to changes in the environment is referred to as genotype (G) x environment (E) interaction or G x E interaction. The primary aim of multi- locational trial in plant breeding is to estimate yield of genotypes across diverse environments. Differential genotypic response to variable environmental conditions associated with changes in ranking of genotypes may limit accurate yield estimation and identification of high yielding stable genotypes (Ajibade *et al*., 2003). Genotype–environment interactions have long been considered important to agriculture and animal breeding generally because the genetic architecture for traits, and thus evolutionary dynamics, vary with environmental conditions (Ouborg *et al*., 2010). Russell (1991) and Duvick (2005) reported that improvements in hybrid corn yield are due to both breeding and cultural practices. Thus yield gains are caused by changes in cultural practices and by contributions of plant breeding. The two categories however interact;

yield gains from changes in cultural practices (such as weed and pest control, timeliness of planting and increased efficiency of harvest equipment) are dependent on changes in breeding, and vice versa. Genotype improvement is given credit for about half of yield improvement with agronomic management accounting for the remainder (Duvick, 1986; 2005). Duvick (2005) found that late sowing reduced number of ears per plant, number of grains per ear and grain yield. Genotype x environment interaction may be due to differences in soils, rainfall distribution, seasons and years (Ewool, 2004). Environmental conditions, such as rainfall are unpredictable and difficult to estimate compared to repeatable conditions such as general climate and soil (Cooper *et al*., 1995). In several breeding programs, environments are classified based on cultivar performance and evaluated in a broad range of environments, focusing on the effects of genotype by environment interaction (Cooper *et al*., 1995). In order to reduce G x E interaction effects, several workers have stratified the testing zones into recommended domains. Such stratifications are based on climatic data such as rainfall, temperature or growing degree days that define the length of the growing season in a particular environment (Cooper *et al*., 1995). In an experiment conducted by Sallah *et al*. (2002) on the potential of elite maize composites for drought tolerance in stress and non-drought environments effects, G x E interaction were highly significant for grain yield, 50% silk emergence, plant height, lodging, ears per plant, and ear rating in both drought and non-drought stressed environments. From their stress environment, grain yields of the varieties ranged from 2.21 to 3.12 t ha^{-1}, while in the favorable environment yields for the same varieties ranged from 4.17 to 5.96 t ha^{-1}.

Souza *et al.* (2009) also registered non-significant differences for the genotype x environment interaction for the characters; stand density, number of ears with kernels, ear to plant height relationship and number of broken or lodging plants, showing that these are inherent characteristics of the varieties. Moreover, for the characters; plant height, grain yield and anthesis- silking interval there was a genotype x environment interaction, showing that there is variability among the progeny between the locations used. Ewool (2004) reported high significance for genotype by environment interaction for grain yield and other agronomic characters. Genotype by environment interaction were highly significant for grain yield, days to mid silk, days to mid-anthesis, plant height, ear height, total lodging, rust, blight, cob aspects, shelling percentage, dry stover weight, 1000 seed weight, cob length, grain depth, grain diameter, anthesis silking interval and cob diameter.

G x E interactions are of interest to plant breeders because of their influence on progress from selection (Sallah *et al*., 2002). The existence of large G x E interaction poses a major problem in relating phenotypic performance to genotypic constitution and hampers effective discrimination among contending genotypes (Comstock and Moll, 1963). It is therefore important to know the nature of G x E interaction to be able to design efficient strategies for testing and selecting superior genotypes, especially when new hybrids are introduced into agriculture.

2.6 Economic benefits derived from replacement of OPVs with hybrid maize varieties

Simtowe *et al.* (2010) reported that yield advantages associated with cultivation of hybrid seeds with fertilizer translate into economic advantages, suggesting that growing of hybrid maize is advantageous in several aspects. In a partial budget analysis of data from 1989 to 1993 they observe that hybrid maize was more profitable to farmers under several seed pricing scenarios and management environments than OPVs. Pixley and Banziger (2001) reported that the use of OPVs and recycled hybrids seeds instead of F_1 hybrids is a backward step for improving grain yield economically.

Chiduza *et al.* (1994) also estimated net benefit from use of hybrid or OPV seeds with or without fertilizer at two remote rural communities in Zimbabwe where cost of hybrid seeds were relatively higher than those in Harare. They found out that, use of OPV seeds together with fertilizers gave the highest net benefit followed by hybrid seeds with fertilizer. It was recommended that when reliable access to hybrid seed is available at similar cost as in Harare, hybrid seed cultivation with fertilizer will be of higher economic advantage. In Ghana, Ewool (2004) reported 2176% Marginal Rate of Return (MRR) for the replacement of local varieties with hybrid under no nitrogen fertilizer and an additional MRR of 194% for cultivation of hybrids under 45 kg N ha^{-1}.

2.7 Genetic correlation between grain yield and other traits

Several workers have attempted to determine linkage between the characters on which the selection for high grain yield can be based. Annapurna *et al*. (1998) found that seed yield was significantly positively correlated with plant height, ear diameter, number of seeds per row and number of rows per cob. You *et al*. (1998) reported significant correlations between yield and number of rows per cob, number of grains per row and 1000-grain weight and also number of grains per row and number of rows per cob. Khatun *et al*. (1999) observed that grain yield per plant was positively and significantly correlated with 1000-grain weight, number of kernels per cob, ear weight and ear insertion height. Orlyan *et al*. (1999) found that the most important traits influencing grain yield are number of grains per row and number of grains per cob. Characters like number of grains per row, 1000-grain weight, and cob diameter and plant height are useful in improving grain yield in hybrids. Maximum correlation of grain yield was obtained with number of kernels per row followed by plant height and cob length (Gautam *et al*., 1999).

In a study conducted by Sallah (1998) on the performance of some open-pollinated maize cultivars in the Guinea savanna he found that One thousand seed weight, stover weight and ears per plant had significant positive correlations with grain yield whereas ear rating and total lodging were negatively correlated with yield. Mikel (2008) found significant increases per breeding cycle for inbred grain yield (6%), plant height (2.3%), ear height (2.2%), and kernel weight (3%), but ear length decreased 4%. Hybrid grain yield increased 2.2% per breeding cycle. A positive correlation (0.36) was found between inbred and hybrid grain yields.

Russell (1991) summarized 13 independent estimates of genetic yield gains of sequentially released maize hybrids in the U.S. The estimates were reported during the 20-year period 1971 through 1991. All of the experiments showed positive genetic yield gains. Estimates ranged from 33 to 92 kg ha^{-1} yr^{-1} with a mean of 66 kg ha^{-1} yr^{-1}. Additional estimates of genetic gain in hybrids have been made since Russell's review. Duvick (1997) stated that an Iowa-adapted time-series of hybrids representing the period from 1930 through 1991 showed a linear gain for grain yield of 74 kg ha^{-1} yr^{-1}. A further update extended this time-series through the year 2001; it showed an estimated linear gain of 77 kg ha^{-1} yr^{-1} (Duvick *et al.*, 2004b). Overall, these estimates indicate that linear genetic gains in grain yield have approximated 65 to 75 kg ha^{-1} yr^{-1} during the past 70 years of hybrid breeding.

Duvick *et al*. (2004a & b) have documented results from studying a selection of maize cultivars grown in the United States Corn Belt from the beginnings of hybrid maize agriculture (1930s) through to the present. Genetic gains of approximately 80 kg ha^{-1} yr^{-1} were measured, contributing approximately 50% of total yield gains. Studies of maize hybrids grown in France show similar genetic gains measured in hybrids grown between 1950 and 1985. Genetic gain for grain yield ranged from 100 kg $ha^{-1}yr^{-1}$ for very early and early hybrids, to 60 kg $ha^{-1}yr^{-1}$ for semi-early hybrids and 80 kg $ha^{-1}yr^{-1}$ for late hybrids (Derieux *et al*., 1987). Barriere *et al*. (1987) measured genetic gain for maize silage biomass improvement. They found a rate of improvement of 70 kg ha^{-1} yr^{-1} for early hybrids but a negative rate of –20 kg ha^{-1} yr^{-1} for mid-early hybrids.

In Ghana, however, Ewool (2004) reported genetic gain of 12.5 to 33.1 kg $ha^{-1}yr^{-1}$ or 0.5 to 1% per year. Sallah (1998) reported that Linear regression estimates of grain yield increases (yield gains) per year were 32.3 kg ha^{-1} at zero-N, 45.1 kg ha^{-1} at 80 kg N ha^{-1}, and 56.4 kg ha^{-1} at 160 kg N ha^{-1}. Linear estimates over the -three N levels were significant and positive for grain yield, days to 50 per cent silk emergence, percent grain moisture content at harvest, and 1000-seed weight, but was negative for ear acceptability rating and percent total lodging. The data also showed that significant progress has been made in genetic improvement of maize in Ghana since breeding programmes were initiated in the mid-1950s; breeding was effective in improving yield potential of maize under low as well as at high levels of soil fertility, and increase in yield potential of the varieties resulted in corresponding increases in size and uniformity of ears, 1000-seed weight and tolerance to lodging.

O'Neill *et al*. (2004) stated that grain yield is a complex quantitative character, highly influenced by environmental fluctuations and is associated with fresh ear weight, shelling percentage, ear diameter, cob length and 100–seed weight. They advised that, before embarking on grain yield improvement it is necessary to understand the relationships existing between grain yield and other metric traits of the crop. Whereas correlation is simply a measurement of mutual association without regards to causation, path coefficient analysis indicates the causes and measures their importance. Path coefficient analysis permits partitioning of the correlation co-efficient into components of direct and indirect causes of association. Both correlation and path coefficient analyses have been studied in maize by Kang *et al.* (1983), in triticale by Sethi *et al*. (1977), in vegetable cowpea by Uguru (1996) and in sugar cane by James (1971). Results revealed that grain yield had positive and highly significant correlation with 100-seed weight, fresh ear weight, cob length, shelling percentage, ear diameter and number of leaves at harvest in both years. This indicated that selection to improve these traits could lead to simultaneous increase in grain yield, though the effectiveness of this would depend on their heritabilities and genetic response of the particular traits to the environment (Jaimini *et al.*, 1974). The positive correlation between 100-seed weight and grain yield in both years of study is in agreement with the findings of Jamini *et al.* (1974). Fresh ear weight was positively and significantly correlated with cob length, shelling percentage, ear diameter, number of leaves at harvest and plant height at harvest in both years, while days to 50% tasselling and silking were negatively correlated with yield and all the yield components. The positive associations imply positive responses in the levels of one character when the other is selected for, while the negative associations indicate the reverse situation. Cob length had negative and low direct effect on grain yield. Its positive correlation with grain yield was mainly due to its indirect effect via fresh ear weight, shelling percentage and ear diameter. Fresh ear weight had a highly significant positive correlation with grain yield as well as high direct effect on yield of 0.511 and 0.637 in 1998 and 1999 respectively, which represented about 55 and 73% of the relationship between grain yield and fresh ear weight, respectively. The remaining 45 and 27% are credited to only the indirect effects through shelling percentage. The relatively large and positive direct effects of fresh ear weight on grain yield in both years indicated that selection for heavy cobs would result in increased grain yield. This finding is in agreement with Kang *et al.* (1983). Also the indirect effects of various traits via fresh ear weight were desirable possibly because heavier or larger cobs are needed to support more grains. Shelling percentage had a positive direct effect on grain yield that was high in 1998 (66%) and moderate in 1999 (40%) – indicating its relative importance in increasing grain yield directly. The remaining 34% and 60% were accounted for by the indirect effect mainly through fresh ear weight as the effects of cob length was however, negative and of no significance in the years of study.

An examination of the partitioning of the correlations into direct and indirect effect components revealed that fresh ear weight, shelling percentage, 100 seed weight and ear diameter were characters that exerted the greatest influence both direct and indirectly upon the maize grain yield. Although, the influence of these four characters varied in the two years of study probably as a result of environmental influence (Reddy and Reddi, 1986), Kang and Miller (1990), the fresh ear weight and shelling percentage were consistent in their direct and indirect contributions to yield in both years. These two traits are therefore, very important components of grain yield and should be given great attention in any selection process aimed at improving grain yield in maize.

Recent introductions of hybrid maize varieties in Ghana in the past two decades necessitated the need to assess progress made in maize production due to genetic improvement programmes and was estimated by Ewool (2004) with improved OPVs, local varieties and hybrids. Eight new maize varieties have been released after this research and hence estimation of genetic gain under three levels of nitrogen application was necessary to compare the relative yielding abilities of OPV and hybrid varieties as well as their stability and performance under high and low nitrogen. This will help predict possible benefits obtainable when farmers engage in cultivation of hybrids instead of OPVs.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Experimental material

Thirteen varieties of maize consisting of 1 local variety, 5 improved open pollinated varieties, 4 inbred lines and 3 hybrid varieties comprising of commercialized varieties were used in the present study. These varieties were obtained from the Crop Research Institute, Kumasi in the Ashanti region of Ghana. The characteristics of the varieties used are summarized in Table 1.

3.2 Experimental sites

The study was carried out in two experimental locations in order to estimate genotype by environment interaction. These were at Kwadaso (6^0 41' N, 1^0 36' W- forest ecology, Coarse sandy-loam Paleustult) and Ejura (7^0 23' N, $1^0$21' W- transition ecology, fine-coarse sandy loam Oxisol), both in the Ashanti region of Ghana, in the major and minor seasons of 2011, respectively.

3.3 Land preparation

The fields were disc- ploughed, harrowed and ridged before planting to achieve a minimum tillage. Glyphosate at 1.5 kg ha^{-1} was also applied two weeks before planting to control pre- emergence weeds.

Table 1. Varieties used in the study and their characteristics

Variety	Year of release	Maturity zone	Varietal type	Reason for release
Etubi	2007	Intermediate	WQPHM	DT
Mamaba	1997	Intermediate	WQPHM	DT
Golden jubilee	2007	Intermediate	YOPV/QPM	QPM
Obatanpa	1992	Intermediate	WOPV/QPM	Yield, QPM
Abontem	2010	Extra- early	YOPV/QPM	STR, Earliness
Akposoe	2007	Extra- early	WOPV/QPM	DT, Earliness
Aburohemaa	2009	Early	WOPV/QPM	DT, STR
Local	1955	late	OPNM	Yield
GH 110	1997	Intermediate	SCH	DT
Entry 5	1997	Intermediate	Inbred line	DT
Entry 6	1997	Intermediate	Inbred line	DT
Entry 70	1997	Intermediate	Inbred line	DT
Entry 85	2007	Intermediate	Inbred line	DT

Source: Sallah *et al*. (2004); Ewool (2004); Variety release (2007 & 2010).

WQPHM: white quality protein hybrid maize, YOPV: yellow open pollinated variety, QPM: quality protein maize, WOPV: white open pollinated variety, OPNM: open pollinated normal maize, SCH: single cross hybrid, DT: drought tolerant, STR: *Striga hermontica* resistance.

3.4 Soil analysis.

Soil analysis was carried out on soil samples taken before nitrogen application to ascertain the nutrient level of the soils in the two locations for better result interpretation.

3.5 Field layout and treatments

The experimental design was 3 x 13 split plot experiment arranged in RCBD with three nitrogen levels as main- plot factor and 13 varieties as sub-plot factor. The treatment combinations were replicated four times in each location. Three nitrogen levels N_1; 0 kg N ha^{-1}, N_2; 45 kg Nha^{-1} and N_3; 90 kg N ha^{-1} were applied to all 13 maize varieties (Table 1) in each location, resulting in 39 treatment combinations. These levels of nitrogen treatment factor were applied in 2 splits with the first half applied at 2 weeks after planting (WAP) and the second split at 4 WAP. Each plot consisted of two rows, 5 m long, spaced at 0.75 m apart with 0.225 m between plants within a row in both locations. Planting was done at three seeds per hill and later thinned to one plant per hill. Application of 60 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1} was done as basal fertilizer in addition to the different nitrogen levels. Weeding by hoe was done three times at three weekly intervals after planting to control post- emergence weeds in both locations and to maintain weed- free fields.

3.6 Data collection

Data were recorded in both locations on days to 50% silking, as the number of days from planting to when 50% of the plants had emerged silks, and days to anthesis when 50% had shed pollen. The anthesis-silking interval (ASI) was calculated as the difference between days to 50% silking and 50% anthesis. Plant height was measured as the distance from the base of the plant to the height of the first tassel branch and ear height as the distance to the node bearing the upper ear respectively. Root lodging (percentage of plants leaning more than 30^0 from the vertical), and stalk lodging (percentage broken at or below the highest ear node), and ear aspect (based on a scale of 1 to 5, where 1; clean, uniform, large, and well-filled ears and 5; ears with undesirable features), were also recorded. Ear number per plant was obtained by dividing the total number of ears per plot by the number of plants harvested. Open tip was counted as cobs with less than two-third of their tips covered with grains. Harvested ears from each plot were shelled to determine the moisture content in percentage. Number of rotten ears was counted as cobs with more than a third of their kernels rotten. Streak, and blight on a scale of 1 to 5, 1; absence of disease and 5; severe infection. Cob length was measured after dehusking the ear. Cob diameter, grain length, grain diameter grain width and grain thickness were measured by using a Veneer caliper. Weights of 1000 grains were also recorded for each treatment.

Grain yield was computed from field weight (kg/m^2), adjusted to 15% moisture content and 80% shelling percentage (Salami *et al*., 2003)

3.7 Data analysis

Analysis of variance (ANOVA) was performed on collected data separately for each environment and later combined across locations using GenStat Statistical package version 9. Count data were transformed before analysis was done using square root transformation. Mean separation was done using Least significant difference (Lsd) at 5%. Yield data was subjected to genotype main effect and genotype by environment interaction (GGE) biplot analysis to assess yield stability among the maize varieties.

Table 2. Format of analysis of variance for combined locations

Source of variation	Degree of freedom (Df)
Location (L)	L- 1
Replication (r)	(r-1)
Nitrogen (N)	N- 1
L x N	(L-1)(N-1)
Error (a)	L(r-1)(N-1)
Genotype (G)	G-1
G x L	(G-1)(L-1)
G x N	(G-1)(N-1)
G x L x N	(G-1)(L-1)(N-1)
Error (b)	LN(r-1)(G-1)

CHAPTER 4

4.0 RESULTS

4.1 Nutrient status of experimental site before planting

Results of initial soil properties of experimental fields at Kwadaso and Ejura in the major and minor seasons respectively in 2011 are presented in Table 3. Nutrient status, in accordance with Landon (1991) interpretation of analyzed soils, is generally low in both locations except for phosphorus level which was very high at Kwadaso. However, soil at Kwadaso was better than that of Ejura. Nitrogen levels (Table 3) were considered low in both locations since amounts less than 0.5% were recorded, hence it is expected that results obtained in the study would project the true response of genotypes to nitrogen applied externally.

Table 3. Soil chemical properties of experimental sites at 0 - 15 cm and 15 - 30 cm soil depths for 2011

	Kwadaso		Ejura		Landon (1991) interpretation	
Soil Properties	0 -15 cm	15- 30 cm	0 -15 cm	15- 30 cm	High	Low
pH (1:1)	6.32	5.53	5.52	5.27	>6.5	<5.8
Organic C (%)	0.94	0.51	0.41	0.41	>10.0	<4.0
Total N (%)	0.09	0.04	0.04	0.04	>0.5	<0.2
Ex Ca ($Cmol_c$/kg)	4.27	3.47	3.20	1.87	>10.0	<4.0
Ex Mg ($Cmol_c$/kg)	1.07	0.80	1.25	0.94	>4.0	<0.5
Ex K ($Cmol_c$/kg)	0.42	0.34	0.10	0.09	>0.6	<0.2
Ex Na ($Cmol_c$/kg)	0.36	0.21	0.09	0.09	>1.0	<1.0
Av P (Mg/kg)	261.50	64.50	5.95	5.02	>50.0	<15.0

Ex: Exchangeable, Av: Available

4.2 Analysis of variance of yield and agronomic traits

The combined analysis of variance (ANOVA) for all 13 genotypes evaluated at Kwadaso and Ejura under three nitrogen levels in the major and minor seasons respectively of 2011 revealed highly significant ($P< 0.05$) genotype (G) mean square values for grain yield and all other agronomic traits measured except for ears per plant and grain thickness (Tables 4 and 5). Similarly, location (L) showed highly significant mean square values for grain yield and all other agronomic traits considered but not 1000 seed weight. The combined ANOVA also produced highly significant nitrogen (N) mean square values for grain yield, days to mid anthesis, days to mid silking, anthesis silking interval (ASI), cob aspects, plant height, streak disease, ears per plant, shelling percentage and stalk lodging and for open tip $P<0.05$ (Tables 4 and 5). The interactions between G, L and N showed highly significant mean square values for gain yield.

4.3 Grain yield

Combined ANOVA showed that genotypes were significantly different in their grain yielding abilities. Averaged across test environments (i.e. location by nitrogen levels), 'Mamaba', a Quality Protein Maize (QPM) hybrid recorded the highest mean grain yield of 4.73 t ha^{-1} which was significantly different from the mean grain yield of remaining varieties except 'Etubi' (Table 6). 'Entry 6' which is an inbred line recorded the lowest grain yield of 0.51 t ha^{-1}. Mean grain yield was significantly higher at Kwadaso (3.16 t ha^{-1}) than Ejura (2.61 t/h). With respect to nitrogen levels, generally, all genotypes

Table 4. Mean sum of squares from combine ANOVA of 13 genotypes for grain yield and all agronomic traits considered under 3 nitrogen levels in Kwadaso and Ejura in major and minor seasons respectively in 2011

Source	Df	Grain Yield (t ha^{-1})	1000 seed weight (g)	Mid anthesis (days)	Mid silking (Days)	ASI (Days)	Blight disease (score)	Cob aspects (score)	Cob diameter (cm)	Plant height (cm)	Rotten ears (%)	Root lodge (%)
Rep	3	2.8**	6592*	92.8**	72.2**	8.6**	12.9**	1.3**	0.7**	724**	2105.5**	465.1**
Genotype (G)	12	44.1**	12207**	122.8**	152.6**	3.4**	0.8**	0.8**	1.8**	2706.7**	577.7**	52.1*
Location (L)	1	11.8**	2764NS	1235.4**	785.3**	50.8**	72.0**	6.4**	2.9**	5261.8**	10665.1**	1051.7**
Nitrogen (N)	2	42.4**	2643NS	248.0**	519.5**	49.9**	0.08NS	1.2**	0.04NS	11039.9**	38 NS	61.8NS
L x N	2	0.9**	2569NS	23.2**	49.8**	6.4**	0.04NS	5.4**	0.2NS	1267.9**	20.1NS	9.9NS
L x G	12	0.5**	415NS	27.9*	29.7**	1.1NS	0.4NS	0.4NS	0.2**	912.6**	336.8**	26.0NS
N x G	24	0.9**	1660NS	5.7NS	4.1NS	1.5*	0.2NS	0.2NS	0.08NS	88.3NS	110.7NS	19.9NS
L x N x G	24	0.1**	45487NS	186.8**	228.0**	24.8NS	2.6NS	5.9NS	2.4NS	3971NS	1303.5NS	306.2NS
Pooled error	153	0.04	1786	4.0	4.7	0.9	0.24	0.25	0.08	170.6	109.0	26.1

**, significance at 1%; *, significance at 5%; NS, non-significance.

Table 5. Mean sum of squares from combine ANOVA of 13 genotypes for grain yield and all agronomic traits considered under 3 nitrogen levels in Kwadaso and Ejura in major and minor seasons respectively in 2011 (cont'd)

Source	Df	Cob length (cm)	Ears per plant	Ear height (cm)	Streak (score)	Grain length (cm)	Grain thickness (cm)	Grain width (cm)	Open tip (%)	Shelling percent (%)	Stalk lodging (%)
Rep	3	4.2NS	1.8**	3108NS	1.5NS	0.1**	0.004NS	0.03**	9496.4**	44.2NS	10883.4**
Genotype (G)	12	18.4**	0.1NS	2323*	2.02*	0.1**	0.003NS	0.03**	854.7**	773.4**	882.9**
Location(L)	1	8.7**	14.8**	8229*	19.98**	0.4**	0.05**	0.14**	34880.5**	582.9**	42823.1**
Nitrogen (N)	2	4.6NS	1.0**	2154NS	4.9**	0.0NS	0.001NS	0.00NS	731.9*	1642.1**	6131.6**
L x N	2	11.3**	0.1NS	1824NS	2.5NS	0.0NS	0.0NS	0.002NS	548.5NS	60.6NS	3237.4**
L x G	12	10.8**	0.1NS	667NS	1.0NS	0.011NS	0.01*	0.003NS	201.8NS	52.6NS	420.3*
N x G	24	1.5NS	0.04NS	1052NS	1.1NS	0.01NS	0.002NS	0.004NS	240.4NS	110.5**	247NS
L x N x G	24	41.1NS	0.7NS	19887NS	0.3NS	0.2NS	0.13**	0.16NS	5522.1NS	615.4NS	3308.5NS
Pooled error	153	2.1	0.05	1240	0.59	0.01	0.002	0.005	201.8	39.9	229.1

**significance at 1%, * significance at 5%, NS non-significance.

Table 6 Mean grain yield of 13 maize genotypes evaluated in six environments in 2011

		Environments						
		Ejura			Kwadaso			
Genotype	Variety Type	0 kg N ha^{-1}	45 kg N ha^{-1}	90 kg N ha^{-1}	0 kg N ha^{-1}	45 kg N ha^{-1}	90 kg N ha^{-1}	Means
Abontem	OPV	2.61	3.38	4.40	3.26	4.35	5.19	2.86
Aburohemaa	OPV	2.49	3.02	3.56	2.97	3.12	4.84	2.33
Akposoe	OPV	2.64	2.90	3.30	3.17	3.62	4.13	2.29
Obatanpa	OPV	2.30	3.67	4.13	2.63	3.72	4.64	2.51
Golden J	OPV	2.34	3.24	4.21	3.48	4.12	5.10	2.91
Entry 5	Inbred	0.28	0.56	0.90	0.49	0.62	1.49	0.72
Entry 6	Inbred	0.20	0.37	0.69	0.31	0.69	0.84	0.51
Entry 70	Inbred	0.67	0.90	1.36	1.01	1.66	2.06	1.28
Entry 85	Inbred	0.48	0.80	1.09	0.54	1.12	1.29	0.88
Etubi	Hybrid	3.01	3.89	5.02	3.88	5.51	6.72	4.67
GH 110	Hybrid	3.00	3.87	4.49	3.33	4.32	5.52	4.09
Mamaba	Hybrid	3.21	4.07	5.30	3.71	5.25	6.83	4.73
Local	Local	2.01	2.43	3.01	2.33	2.51	3.58	1.14
Means		1.94	2.54	3.19	2.39	3.12	4.02	2.38
Lsd (5%)		0.26**	0.26**	0.26**	0.26**	0.26**	0.26**	0.13**
Lsd (5%) #		0.07**						
CV (%)		7.66						

For comparison of environments means;**significance at 1%.

considered showed appreciable increases in yield in response to increases in nitrogen level from 0 – 90 kg N ha^{-1}. No negative response was recorded for grain yield in any genotype, indicating that yield increase was directly proportional to nitrogen levels and was observed in the order of 0 kg N ha^{-1} < 45 kg N ha^{-1} < 90 kg N ha^{-1}. Although a very high significant G x N x L interaction was observed for grain yield, there were no changes in the ranks among the genotypes across the test environments in their mean grain yielding abilities except for Kwadaso under 0 kg N $ha^{-1}$and 45 kg N ha^{-1} where 'Etubi' slightly out-yielded 'Mamaba' (Table 6). The highest mean grain yield was recorded at both locations with ranges in mean grain yield from 0.69 – 5.30 t ha^{-1} at Ejura and 0.84 – 6.38 t ha^{-1} at Kwadaso. The lowest mean grain yield was produced at 0 kg N ha^{-1} Ejura and Kwadaso test environments, where ranges in mean grain yield were from 0.2 – 3.21 t ha^{-1} and 0.31 – 3.88 t ha^{-1} at Ejura and Kwadaso respectively.

4.4 Relative yielding abilities and stability of genotypes in test environments

A GGE biplot analysis was carried out in which environments were designated as combinations of the two locations (Ejura and Kwadaso) and three nitrogen levels (0 kg N ha^{-1}, 45 kg N ha^{-1} and 90kg N ha^{-1}) resulting in six test environments in accordance with Beets' (1982) definition of an environment as all microclimatological and physical factors such as water, temperature, soil conditions and all other factors that affect plants growth, development and yield. In the GGE biplot analysis, Principal Components 1 and 2 (PC1 and PC2) together explained 99% of variation in grain yield. Thus 99% of the variation in yield was due to genotype and genotype by environment effects (Figure 1).

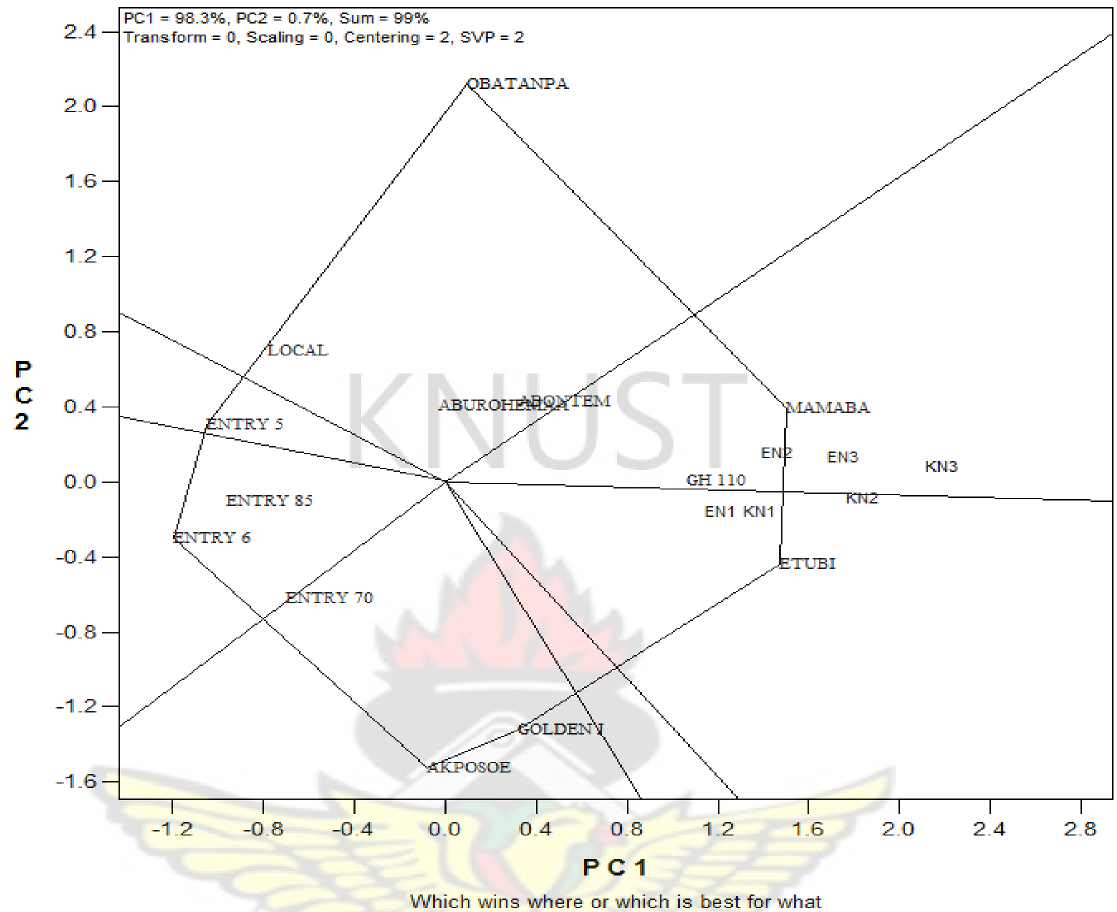

Fig.1. A 'which won where' GGE biplot of grain yield for 13 genotypes under six environments as EN1 (Ejura under 0 kg N ha^{-1}), EN2 (Ejura under 45 kg N ha^{-1}), EN3 (Ejura under 90 kg N ha^{-1}), KN1 (Kwadaso under 0 kg N ha^{-1}), KN2 (Kwadaso under 45 kg N ha^{-1}) and KN3 (Kwadaso under 90 kg N ha^{-1}). The data was not transformed ("Transform=0"), not standardized ("scale =0"), and were environment-centered ("centering =2"). The biplot was based on genotype- focused singular value partitioning ("SVP = 2") and is therefore appropriate for visualizing the relationship among environments. Principal component (PC) 1 and PC2 for model 3 explained 99% of yield variation.

Result from the “which won where” biplot (Figure 1) grouped the six test environments into two mega-environments. The two mega-environments were obtained by grouping Ejura under 90 kg N ha^{-1} (EN3), Ejura under 45 kg N ha^{-1} (EN2), Kwadaso under 90 kg N ha^{-1} (KN3) Kwadaso under 45 kg N ha^{-1} (KN2) as one mega- environment, with ‘Mamaba’ as the highest yielding genotype in that environment and Ejura under 0 kg N ha^{-1} (EN1), Kwadaso under 0 kg N ha^{-1} as the other mega environment with ‘Etubi’ as the highest yielding genotype.

In the ranking of genotypes based on the mean yield and stability GGE biplot (Figure 2), the double arrowed vertical (blue) line Average Tester Coordinate (ATC ordinate or y axis) measures stability whiles the average yield of a cultivar is approximated by its position on the ATC abscissa or x- axis (the single arrowed horizontal red line). The red circle on the ATC abscissa is the average tester yield, thus ‘Etubi’, ‘Mamaba’ and ‘GH 110’ yielded above the average tester yield (Figure 2). The stability of a cultivar is measured by their projection onto the ATC ordinate, thus the greater the projection of the cultivar the less stable it is (Yan *et al.,* 2007). In the current study, the mean and stability GGE biplot revealed that, ‘Mamaba’ and ‘Etubi’ were the highest yielding and most stable cultivars since differences in their individual stability and yield were not significant from each other. Open pollinated varieties (OPVs) had the second highest mean grain yield and were averagely stable but ‘Obatanpa’ was the least stable among all the cultivars considered. The inbred lines and local varieties were the lowest yielding genotype but were the most stable, following Yan *et al.* (2007) interpretation. Figure 3 shows the discriminating power and representativeness of the six test

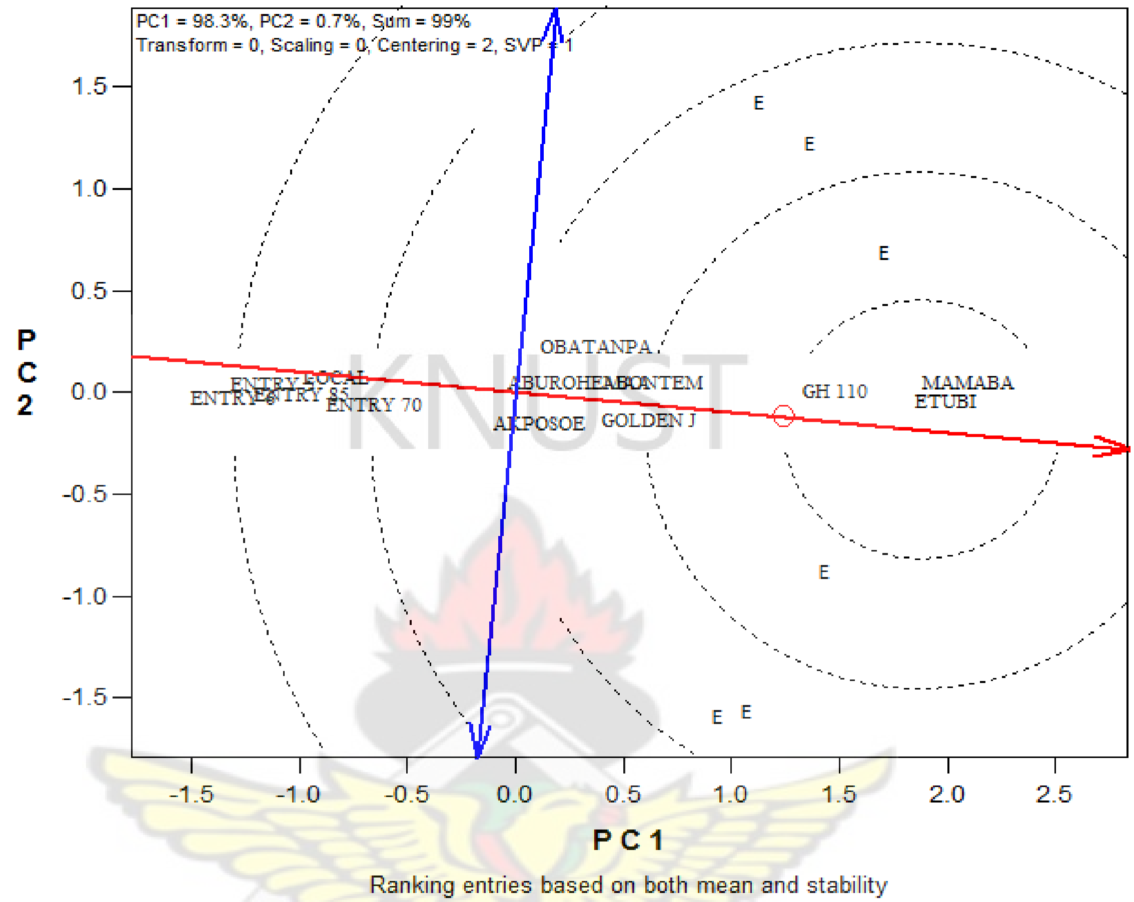

Fig.2. Ranking of genotypes based on mean and stability GGE biplot of grain yield for 13 genotypes under six environments (EN1 (Ejura under 0 kg N ha^{-1}), EN2 (Ejura under 45 kg N ha^{-1}), EN3 (Ejura under 90 kg N ha^{-1}), KN1 (Kwadaso under 0 kg N ha^{-1}), KN2 (Kwadaso under 45 kg N ha^{-1}) andKN3 (Kwadaso under 90 kg N ha^{-1}). The data was not transformed ("Transform=0"), not standardized ("scale =0"), and were environment-centered ("centering =2"). The biplot was based on genotype- focused singular value partitioning ("SVP = 2") and is therefore appropriate for visualizing the relationship among environments. Principal component (PC)1 and PC2 for model 3 explained 99% of yield variation.

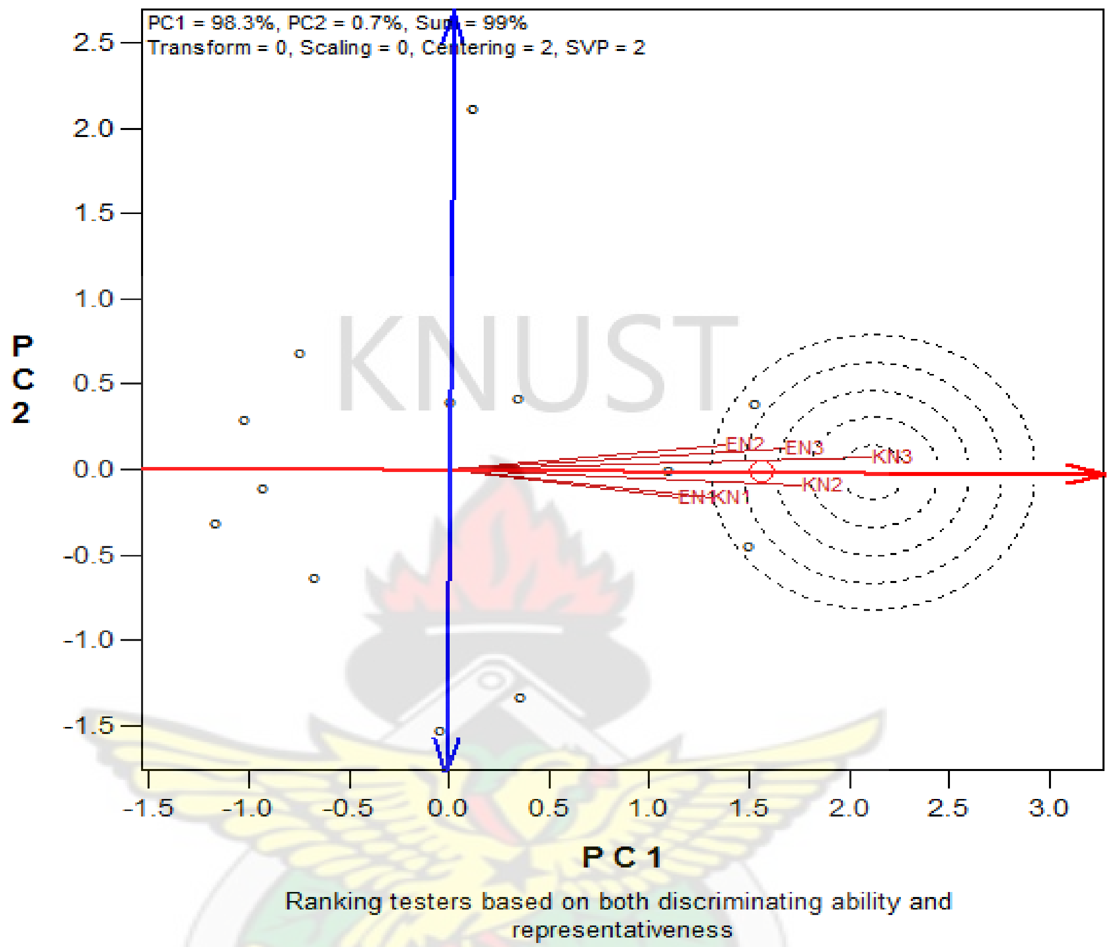

Fig.3. Ranking of test environment based on both discriminating ability and representativeness GGE biplot of grain yield for 13 genotypes under six environments (EN1 (Ejura under 0 kg N ha^{-1}), EN2 (Ejura under 45 kg N ha^{-1}), EN3 (Ejura under 90 kg N ha^{-1}), KN1 (Kwadaso under 0 kg N ha^{-1}), KN2 (Kwadaso under 45 kg N ha^{-1}) andKN3 (Kwadaso under 90 kg N ha^{-1}). The data was not transformed ("Transform=0"), not standardized ("scale =0"), and were environment-centered ("centering =2"). The biplot was based on genotype- focused singular value partitioning ("SVP = 2") and is therefore appropriate for visualizing the relationship among environments. Principal component (PC)1 and PC2 for model 3 explained 99% of yield variation.

environments considered and its appropriateness for studying the relationship between the test environments. It thus helps in selecting the ideal test environment for testing the 13 genotypes considered. An ideal test environment explained by Yan *et al.* (2007) should be both discriminating of the genotypes as well as representative of the mega-environment. According to Yan (2002), test environments with long vectors as observed for KN3 (Kwadaso under 90 kg N ha^{-1}) in the present study, are more discriminating of genotypes while those with short vectors (e.g. EN1; Ejura under 0 kg N ha^{-1}) are less discriminating and provide little information on the genotype yield differences. In terms of representativeness, KN3 is more representative of the mega-environments as it has the smallest angle of deviation with the single- arrowed axis (Yan *et al*, 2007). Since test environment KN3 has the longest vector and smallest angle, it provides unique information and is therefore ideal for selecting superior genotypes.

4.5 Comparative grain yield performances of hybrids, OPVs and inbred lines

In the present study, mean grain yield for QPM hybrids, OPVs, local varieties and inbred lines were 4.67 t ha^{-1}, 3.67 t ha^{-1}, 2.90 t ha^{-1} and 0.90 t ha^{-1} respectively when averaged across nitrogen levels and locations (Table 6). From Figure 4, Hybrids recorded 16.6% and 55.4% yield advantage over OPV and local varieties respectively at 0 kg N ha^{-1}. OPVs on the other hand recorded 33.3% yield advantage over local varieties. At 45 kg N ha^{-1}, hybrids recorded 29.7% and 88% yield advantage over OPVs and local varieties respectively. OPVs on the other hand recorded 45.2% yield advantage over local varieties. At 90 kg N ha^{-1}, hybrids recorded 30.9% and 73.45%

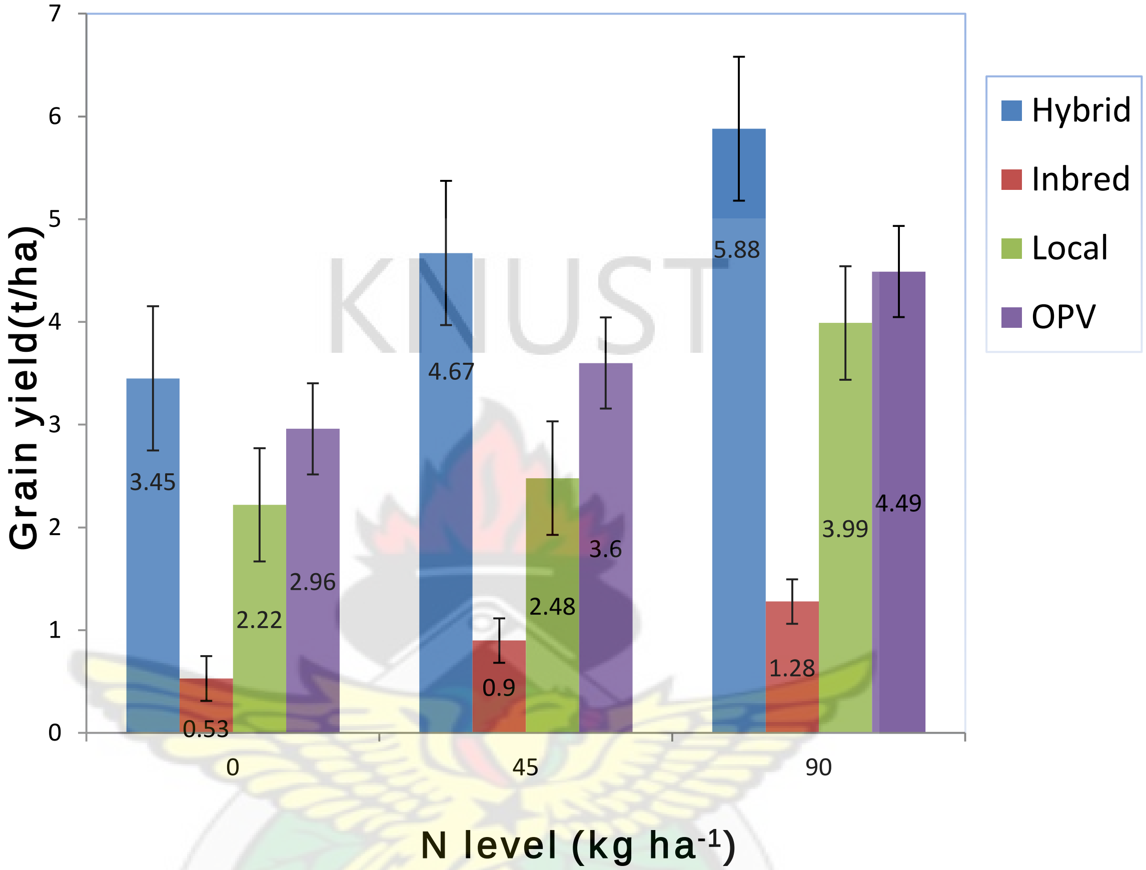

Fig.4. Mean grain yield of OPVs, inbred lines, local varieties and hybrids evaluated under 3 nitrogen levels at Kwadaso and Ejura in the major and minor seasons respectively in 2011

yield advantage over OPVs and local varieties respectively whiles OPVs consequently recorded 32.45% yield advantage over local varieties. Generally, it was apparent that, Hybrids' yield advantages over OPVs increased sharply with increase in nitrogen level from 0 kg N ha^{-1} to 45 kg N ha^{-1} but at 90 kg N ha^{-1} difference in yield advantage was not significant from that of 45 kg N ha^{-1}.

4.6 Heterosis estimates of hybrids

Heterosis estimates of hybrids calculated on high parent value basis using mean grain yield of genotypes recorded in Table 6 are presented in Table 7 below. 'Mamaba' recorded the highest heterosis value of 269.53% ahead of 'Etubi' (264.84%) and GH110 (219.53%).

Table 7. Heterosis of three hybrids varieties planted at Ejura and Kwadaso in the minor and major seasons respectively under three nitrogen levels in 2011

Hybrid	Type of cross	Inbred parents	Inbred parental yields (t ha^{-1})	Heterosis (%)
GH 110	single	Entry 6	0.51	219.53
		Entry 70	1.28	
Mamaba	Three way	Entry 6	0.51	269.53
		Entry 70	1.28	
		Entry 5	0.72	
Etubi	Three way	Entry 6	0.51	264.84
		Entry 70	1.28	
		Entry 85	0.88	

Heterosis calculated on High parent basis

4.7 Other agronomic traits

Shelling percentage

The combine ANOVA showed significances in genotypes for shelling percentages. Shelling percentages of genotypes are presented in Table 8 Local varieties recorded the highest shelling percentage of 79.38% whilst 'entry 5' had the smallest shelling percentage of 57.52%. Nitrogen was significant ($P \leq 0.05$) for shelling percentage with decreasing percentages with increasing nitrogen level in all genotypes except for local

Table 8. Mean shelling percentages of 13 maize genotypes evaluated in Ejura and Kwadaso in the minor and major seasons of 2011 respectively.

Genotype	Variety Type	Locations						Means
		Ejura			Kwadaso			
		0 kg N ha^{-1}	45 kg N ha^{-1}	90 kg N ha^{-1}	0 kg N ha^{-1}	45 kg N ha^{-1}	90 kg N ha^{-1}	
Abontem	OPV	73.95	69.14	58.06	76.93	71.57	60.82	68.86
Aburohemaa	OPV	73.00	66.62	54.69	75.99	69.15	56.34	66.36
Akposoe	OPV	73.61	64.4	56.58	76.73	67.18	56.34	66.12
Obatanpa	OPV	73.02	67.52	54.46	76.79	69.04	57.12	66.77
Golden J	OPV	63.84	66.58	64.59	59.82	69.36	57.12	63.07
Entry 5	Inbred	60.44	52.35	49.68	63.77	52.91	60.93	57.52
Entry 6	Inbred	61.08	53.26	48.21	64.68	55.99	57.07	57.56
Entry 70	Inbred	61.52	53.8	51.67	63.77	57.9	54.98	57.81
Entry 85	Inbred	60.57	57.8	49.56	63.77	64.21	52.39	58.74
Etubi	Hybrid	68.57	63.79	49.69	71.1	72.79	75.37	68.95
GH 110	Hybrid	70.73	67.67	60.43	72.69	75.29	72.79	71.15
Mamaba	Hybrid	70.56	67.04	63.08	71.74	71.82	74.57	70.77
Local	Local	79.53	78.75	78.86	80.03	79.1	79.5	79.38
Means		68.49	63.75	56.89	70.6	67.41	62.72	65.62
Lsd (5%)		8.82NS	8.82NS	8.82NS	8.82NS	8.82NS	8.82NS	4.16**
Lsd (5%) #		2.45NS						
CV (%)		9.63						

#, For comparison of location by nitrogen means; **, significance at 1%; NS, non significance

variety which did not record a regular response to nitrogen. Mean shelling percentages of 69.90%, 66.19% and 60.78% were observed for 0, 45 and 90 kg N ha^{-1} respectively. Location was significant with Ejura recording 63.04% and Kwadaso recording 66.91%. Nitrogen by variety interaction was significant; local varieties had the highest shelling percentages at all nitrogen levels. Under 0 kg N ha^{-1}, local varieties had 12.22% and 9.97% advantage over hybrids and OPVs respectively. Under 45 kg N ha^{-1}, local varieties recorded11.42% and 15.33% advantage over hybrids and OPVs, respectively. Under 90 kg N ha^{-1}, local varieties recorded 15.45% and 37.67% advantage over hybrids and OPVs respectively. Genotype by location and genotype by location by nitrogen interactions were not significant (Figure 5).

Mean days to mid anthesis

Combined ANOVA showed that genotypes were significantly different in their mean number of days to anthesis. Generally, 'Akposoe' (51days) had the shortest mean number of days to anthesis whist local varieties (59 days) recorded the longest mean number of days to anthesis (Table 9). Location was significant for days to mid anthesis with Ejura recording 52 days while Kwadaso had 58 days mean number of days to anthesis. Nitrogen level was also significant resulting in shorter of days with increasing nitrogen levels from 0 – 90 kg N ha^{-1}. Location by variety interaction was significant; at Ejura, 'Aburohemaa' had the shortest anthesis date of 48 but at Kwadaso the shortest of 51 days was recorded for 'Akposoe'. Nitrogen by variety interaction was not significant. Location by nitrogen by variety interaction was significant. Mean days to anthesis was 54, 56, 59 and 57 for OPVs, hybrids, local and inbred lines, respectively. Differences in days to anthesis were not significant between OPVs and hybrids across all nitrogen levels (Table 9).

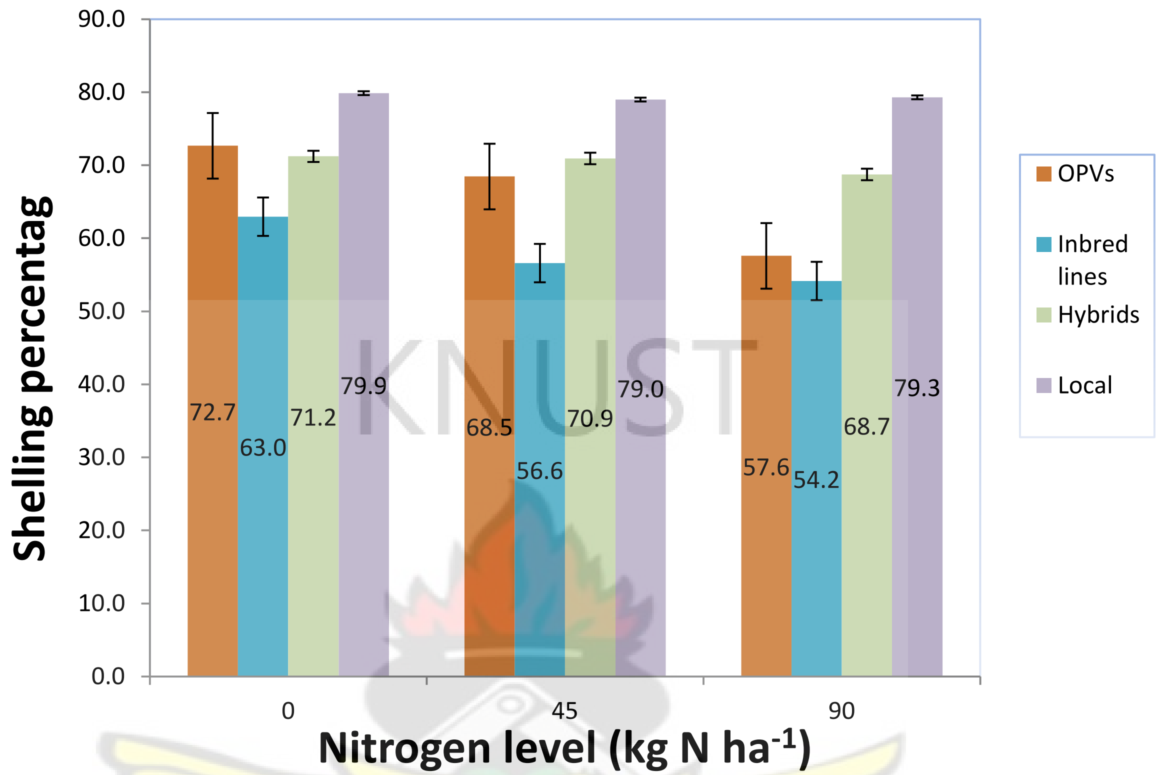

Fig.5. Mean shelling percentages of OPVs, inbred lines, local varieties and hybrids evaluated under 3 nitrogen levels at Kwadaso and Ejura in the major and minor seasons respectively in 2011

Anthesis silking interval (ASI)

Results from the combined ANOVA showed that genotypes were highly significant for ASI. Responses of genotypes to nitrogen levels across locations are presented in Table 10. 'Aburohemaa' recorded the shortest ASI of 3 days whilst 'entry 6'and 'Entry 70' had the longest of 4. Location was significant for days ASI; ASI at Kwadaso was 3 days and 4 days at Ejura. Nitrogen significantly affected ASI, evident in the shorter days recorded with increasing nitrogen levels in both locations. Genotype by nitrogen interaction was

Table 9. Mean number of days to mid- anthesis of 13 maize genotypes evaluated in Ejura and Kwadaso in the minor and major seasons of 2011 respectively.

		Locations						
		Ejura			Kwadaso			
Genotype	Variety Type	0 kg N ha^{-1}	45 kg N ha^{-1}	90 kg N ha^{-1}	0 kg N ha^{-1}	45 kg N ha^{-1}	90 kg N ha^{-1}	Means
Abontem	OPV	52	49	47	56	54	53	53
Aburohemaa	OPV	49	48	48	55	53	52	52
Akposoe	OPV	59	49	46	53	51	50	51
Obatanpa	OPV	58	55	57	59	57	56	57
Golden J	OPV	58	50	48	61	59	58	57
Entry 5	Inbred	57	52	51	62	59	58	57
Entry 6	Inbred	57	55	55	60	60	60	58
Entry 70	Inbred	56	54	55	61	59	60	58
Entry 85	Inbred	50	48	49	57	56	56	54
Etubi	Hybrid	55	49	46	60	58	57	56
GH 110	Hybrid	57	51	49	61	59	57	57
Mamaba	Hybrid	48	52	49	6	57	58	56
Local	Local	59	56	51	63	61	59	59
Means		55	51	50	59	57	56	56
Lsd (5%)		3**	3**	3**	3**	3**	3**	1**
Lsd (5%) #	1**							
CV (%)	3.59							

#, For comparison of location by nitrogen means; **, significance at 1%.

Table 10. Mean ASI of 13 maize genotypes evaluated in Ejura and Kwadaso in the minor and major seasons of 2011 respectively.

Genotype	Variety Type	Location						Means
		Ejura			Kwadaso			
		0 kg N ha^{-1}	45 kg N ha^{-1}	90 kg N ha^{-1}	0 kg N ha^{-1}	45 kg N ha^{-1}	90 kg N ha^{-1}	
Abontem	OPV	6	3	4	4	3	3	3
Aburohemaa	OPV	4	3	2	2	2	2	3
Akposoe	OPV	5	4	3	3	2	2	3
Obatanpa	OPV	5	4	3	4	3	3	4
Golden J	OPV	4	4	4	4	3	3	3
Entry 5	Inbred	5	4	3	3	2	3	3
Entry 6	Inbred	5	4	3	7	3	3	4
Entry 70	Inbred	7	5	4	5	2	3	4
Entry 85	Inbred	6	4	2	4	3	3	4
Etubi	Hybrid	5	3	3	3	3	3	3
GH 110	Hybrid	4	4	2	3	2	3	3
Mamaba	Hybrid	4	4	4	5	3	3	4
Local	Local	7	4	3	4	3	3	4
Means		5	4	3	4	3	3	4
Lsd (5%)		1NS	1NS	1NS	1NS	1NS	1NS	1**
Lsd (5%) #	0.4**							
CV (%)	27.86							

#, For comparison of location by nitrogen means;**, significance at 1%; NS, non significance significant. 'Aburohemaa' recorded the shortest ASI of 3 days across all nitrogen levels (Table 10).Variety groups did not show significant genotype by environment interactions. Genotype by nitrogen by variety interaction was also not significant.

Cob diameter

The combined ANOVA revealed that genotypes were highly significant for cob diameter. Response of genotype for cob diameter is presented in Table 11. 'Obatanpa' recorded the highest cob diameter (4.33 cm) whiles local varieties were the smallest (3.33 cm). Generally, variety groups were significantly different from each other except between OPV and hybrids. Mean cob diameter for OPV, hybrids, local varieties and inbred lines were 3.90, 3.82, 3.30 and 3.40 cm respectively.

There were no significant differences in mean diameter of maize cobs harvested from the two locations; cobs at Ejura were smaller (3.5 cm) than those harvested from Kwadaso (3.80 cm). Nitrogen did not affect cob diameter. Location by variety interaction significantly affected cob diameter; 'Obatanpa' had the highest cob diameter of 4.10 cm and 4.43cm at Ejura and Kwadaso, respectively. Genotype by nitrogen and genotype by nitrogen by location interaction were not significant (Table 11).

Cob length

The combine ANOVA showed that genotypes were significantly different in cob length with 'Obatanpa' recording the highest mean cob length of 14.74 cm while 'Entry 6' produced the shortest mean cobs (10.85 cm). Genotype cob length values are presented in Table 12. Mean cob lengths for hybrids were 14.7% longer than local varieties. Location effect was significant recording means of 12.51 cm and 12.98 cm for Ejura and Kwadaso

Table 11. Mean cob diameter of 13 maize genotypes evaluated in Ejura and Kwadaso in the minor and major seasons of 2011 respectively.

		Locations						
		Ejura			Kwadaso			
Genotype	Variety Type	0 kg N ha^{-1}	45 kg N ha^{-1}	90 kg N ha^{-1}	0 kg N ha^{-1}	45 kg N ha^{-1}	90 kg N ha^{-1}	Means
Abontem	OPV	3.83	2.98	3.18	3.76	3.63	3.66	3.57
Aburohemaa	OPV	3.43	3.83	3.68	4.16	3.94	3.99	3.92
Akposoe	OPV	3.73	3.63	4.08	3.94	4.14	3.89	3.94
Obatanpa	OPV	4.13	3.93	4.23	4.29	4.44	4.56	4.33
Golden J	OPV	3.93	3.83	3.63	3.84	3.84	3.41	3.72
Entry 5	Inbred	3.03	2.63	3.43	3.56	3.64	3.61	3.43
Entry 6	Inbred	2.73	2.88	4.03	2.89	3.11	2.94	3.06
Entry 70	Inbred	3.53	3.73	3.33	3.69	3.81	3.71	3.68
Entry 85	Inbred	3.63	3.13	3.28	3.69	3.71	3.76	3.60
Etubi	Hybrid	3.33	3.68	3.78	3.69	3.66	3.89	3.71
GH 110	Hybrid	3.68	3.48	3.68	3.84	3.91	3.74	3.76
Mamaba	Hybrid	3.58	3.68	3.78	3.86	4.21	4.24	3.98
Local	Local	3.03	2.68	2.83	3.36	3.56	3.59	3.30
Means		3.51	3.39	3.61	3.74	3.82	3.77	3.64
Lsd (5%)		0.39NS	0.39NS	0.39NS	0.39NS	0.39NS	0.39NS	0.18**
Lsd (5%) #	0.11**							
CV (%)	7.56							

#, For comparison of location by nitrogen means; **, significance at 1%; NS, non significance

Table 12. Mean cob length of 13 maize genotypes evaluated in Ejura and Kwadaso in the minor and major seasons of 2011 respectively.

Genotype	Variety Type	Locations						Means
		Ejura			Kwadaso			
		0 kg N ha^{-1}	45 kg N ha^{-1}	90 kg N ha^{-1}	0 kg N ha^{-1}	45 kg N ha^{-1}	90 kg N ha^{-1}	
Abontem	OPV	14.07	10.95	12.00	12.64	13.89	13.29	12.99
Aburohemaa	OPV	10.70	11.80	11.35	11.84	11.69	12.61	11.82
Akposoe	OPV	11.70	11.60	13.45	11.71	12.61	10.96	11.91
Obatanpa	OPV	14.47	13.40	14.97	14.09	15.44	15.26	14.74
Golden J	OPV	12.87	10.70	11.65	12.59	14.11	13.39	12.88
Entry 5	Inbred	12.97	11.67	12.37	12.84	13.86	13.66	13.12
Entry 6	Inbred	10.67	9.70	13.37	9.76	11.06	11.19	10.85
Entry 70	Inbred	11.37	12.57	12.85	13.04	12.76	13.09	12.76
Entry 85	Inbred	10.97	11.60	13.00	12.11	13.51	14.39	12.92
Etubi	Hybrid	13.40	12.10	13.00	12.66	13.84	14.94	13.53
GH 110	Hybrid	14.25	11.20	11.35	12.94	13.44	12.84	12.82
Mamaba	Hybrid	12.35	12.10	13.90	14.74	15.29	15.51	14.47
Local	Local	16.45	15.25	14.05	11.54	10.19	10.76	12.12
Means		12.79	11.90	12.87	12.50	13.21	13.22	12.84
Lsd (5%)		1.67NS	1.67NS	1.67NS	1.67NS	1.67NS	1.67NS	0.96**
Lsd (5%)#		0.56**						
CV (%)		11.33						

#, For comparison of location by nitrogen means; **, significance at 1%; NS, non significance

respectively. Nitrogen did not also affect cob length. Location by variety interaction was significant; the Local variety at Ejura had the highest cob length of 15.23cm whilst 'Mamaba' was the longest at Kwadaso with 15.19cm. Nitrogen by variety and nitrogen by location by variety interactions were not significant (Table 12).

4.8 Mean performance of genotypes for diseases and other yield components

Mean performance of genotypes with respect to 15 other agronomic traits averaged across three nitrogen levels in Kwadaso and Ejura in the major and minor seasons respectively is presented in Table 13. Generally, root lodging was low in hybrids than OPVs and local (check) varieties, however, the differences in root lodging among varietal groups were not significant. Hybrids (247.47 g) had better 1000 seed weight than OPVs (218.48 g) and local varieties (185.30 g). Diseases (blight and streak) were generally lower in hybrid than all other variety groups. Mean number of days to mid silking was shorter in OPVs (57 days) than hybrids (59 days) and local varieties (62 days). Hybrids were generally shorter in plant and ear height than OPVs and local varieties. Generally, hybrids had better cob attributes than OPVs; cob aspect score was better in hybrids in comparison with OPVs and local varieties. Incidence of rotten ears was also lower in hybrids than OPVs but local varieties had the lowest incidence of number of rotten ears per 100 cobs harvested. Highest percent rotten ears were recorded in 'Entry 5'. Cob tips were better filled in hybrids than other varietal groups evident in their lower number of open tips recorded per 100 cobs harvested. Mean of 1 ear per plant was recorded for all genotypes. No significant difference was observed among varietal groups for grain thickness, grain width, and grain length.

Table 13. Mean performances of 13 genotypes for 15 traits in Kwadaso and Ejura in the major and minor seasons respectively under 3 nitrogen levels

Genotype	Variety Type	1000 seed weight (g)	Mid silking (Days)	Blight disease (score)	Cob aspects (score)	Plant height (cm)	Rotten ears (%)	Root lodge (%)	Ears per plant	Ear height (cm)	Streak (score)	Grain length (cm)	Grain thick-ness (cm)	Grain width (cm)	Open tip (cm)	Stalk lodging (%)
ABONTEM	OPV	226.7	55.94	2.56	3.33	147.1	21.80	1.19	0.80	65.06	1.39	0.77	0.27	0.58	38.88	32.70
ABUROHEMAA	OPV	209.6	54.17	2.06	3.39	142.3	17.74	3.33	0.87	92.56	1.33	0.76	0.22	0.61	38.29	30.49
AKPOSOE	OPV	202.7	54.28	1.94	3.17	144.7	12.55	5.97	0.86	60.28	1.89	0.73	0.24	0.60	35.03	33.29
OBATANPA	OPV	219.5	60.61	1.94	3.33	165.6	8.08	6.43	0.73	76.56	1.50	0.83	0.24	0.69	38.85	22.61
GOLDEN J	OPV	233.5	60.17	1.89	3.16	158.5	7.72	4.38	0.87	74.94	1.28	0.84	0.22	0.64	33.01	24.97
ENTRY 5	Inbred	153.2	60.44	1.89	3.55	125.2	22.47	4.25	0.77	53.56	1.11	0.71	0.22	0.56	48.84	23.46
ENTRY 6	Inbred	149.0	62.61	2.06	3.83	127.1	17.03	4.08	0.69	57.11	1.17	0.62	0.24	0.52	51.02	46.98
ENTRY 70	Inbred	162.8	62.17	2.11	3.23	137.2	8.25	2.11	0.81	61.39	1.72	0.73	0.23	0.62	31.27	29.18
ENTRY 85	Inbred	151.1	57.50	1.94	3.28	144.3	14.32	5.68	0.86	68.50	1.39	0.70	0.22	0.55	37.51	20.10
Etubi	Hybrid	248.6	58.83	1.78	3.28	153.3	8.90	4.81	0.73	67.44	1.06	0.75	0.22	0.61	34.99	24.72
GH 110	Hybrid	232.2	59.56	1.71	3.11	139.5	6.06	3.34	0.84	58.33	1.11	0.74	0.22	0.61	26.89	28.87
Mamaba	Hybrid	261.6	59.28	1.72	3.05	146.9	10.38	3.27	0.78	61.61	1.06	0.79	0.23	0.63	32.71	23.48
LOCAL	Local	185.3	62.89	1.89	3.22	162.8	7.14	1.05	0.80	83.83	1.17	0.71	0.23	0.55	30.08	32.99
Means		202.75	59.11	1.96	3.30	145.73	12.50	3.84	0.80	67.78	1.32	0.74	0.23	0.60	36.72	28.76
Lsd (5%)		27.95**	1.42**	0.32**	0.33**	8.60**	6.87**	3.36*	3.36*	23.19*	0.51*	0.07**	0.04NS	0.05**	9.36**	9.97**
CV (%)		19.75	3.66	24.9	15.05	8.96	83.33	93.12	27.93	51.96	27.93	14.41	23.01	12.35	38.69	52.64

**, significance at 1%; *, significance at 5%; NS, non-significance.

4.9 Correlation between grain yield and traits of agronomic importance.

Pearson's moment correlation coefficients between grain yield and twenty other agronomic traits considered in the study are shown in Table 14. Highly significant negative correlations with yield were observed for days to mid anthesis, days to mid silking, ASI and cob aspects. Highly significant positive correlation with grain yield ($P<0.01$) was observed for 1000 seed weight, cob length, grain length, grain width, plant height and shelling percentage and number of ears per plant. Correlations for grain thickness, open tip, root lodging and rotten ears blight disease, cob diameter, ear height, stalk lodging and streak diseases were not significant.

4.10 Economic benefit analysis for hybrids, OPVs and local varieties

Economic analysis for net benefit per hectare, excluding fixed cost and all other farm inputs and labour which were supposedly equal for all variety groups, showed that the lowest net benefit was GH¢1056.00 (US $ 2016.96) for local varieties under 45 kg N ha^{-1} whereas the highest net benefit was GH¢ 2500.80 (US $ 4776.53) for hybrid varieties under 90 kg N ha^{-1} (Table 15). Results from dominance analysis presented in Table 14 indicated that best option for marginal rate returns was hybrids under 90 kg N ha^{-1}. Dominance analysis (Table 16) also showed that, under 0 kg N ha^{-1}, a marginal rate return of 899.87% could be obtained by farmers for cultivating hybrids instead of local varieties, whiles a marginal rate return of 285.9% could be accrued when hybrid varieties are grown under 90 kg N ha^{-1} instead of 0 kg N ha^{-1}.

Table 14. Correlation between grain yield and other agronomic traits.

Trait	Correlation coefficient with grain yield
1000 seed weight(g)	0.26**
Days to mid anthesis(days)	-0.21**
Days to mid silking (days)	-0.27**
ASI(days)	-0.27**
Blight disease (score)	0.10NS
Cob aspect (score)	-0.23**
Cob diameter (cm)	0.06NS
Cob length (cm)	0.32**
Ears per plant	0.17*
Ear height (cm)	0.10NS
Grain length(cm)	0.32**
Grain thickness(cm)	-0.07NS
Grain width (cm)	0.33**
Open tip (%)	-0.07NS
Plant height (cm)	0.43**
Root lodging (%)	-0.04NS
Rotten ears (%)	-0.11NS
Shelling percentage (%)	0.31**
Stalk lodging (%)	0.13NS
Streak disease (score)	0.13NS

**, * correlation coefficient different from zero at $p<0.01$ and $P<0.05$ respectively, NS, non- significance at 5% level probability

Table 15. Economic analysis for net benefit for Local varieties, OPVs and hybrid varieties under three nitrogen levels at Kwadaso and Ejura in the major and minor seasons respectively.

	Variety type								
	Local varieties			OPVs			Hybrids		
	0 kg N ha^{-1}	45 kg N ha^{-1}	90 kg N ha^{-1}	0 kg N ha^{-1}	45 kg N ha^{-1}	90 kg N ha^{-1}	0 kg N ha^{-1}	45 kg N ha^{-1}	90 kg N ha^{-1}
Grain yield (t ha^{-1})	2.22	2.48	3.99	2.96	3.60	4.49	3.45	4.67	5.88
Gross Benefit (GB) Maize price = GH¢ 487.74/ton	1082.78	1209.60	1946.08	1443.71	1755.86	2189.95	1682.70	2277.75	2867.91
Variable Cost (GH¢)									
Seed	0.00	0.00	0.00	0.00	0.00	0.00	60.00	60.00	60.00
Fertilizer	0.00	128.57	257.14	0.00	128.57	257.14	0.00	128.57	257.14
Fertilizer application	0.00	25.00	50.00	0.00	25.00	50.00	0.00	25.00	50.00
Total Variable Cost (TVC)	0.00	153.57	307.14	0.00	153.57	307.14	60.00	213.57	367.14
Net Benefit (GH ¢) ha^{-1} (GB- TVC)	1082.78	1056.03	1638.94	1443.71	1602.29	1882.81	1622.70	2064.18	**2500.77**

Seed rate was calculated at 20 kg ha^{-1} and GH¢ 3.00 per kg for hybrids; farmers engaging in OPV and local varieties cultivation assumed to use saved seed from previous growing season. Cost of Sulphate of ammonia (S/A) per 50 kg plus transport was estimated at GH¢ 30.00; S/A contains 21% N resulting in 10.5 kg N per 50 kg S/A, hence 1 kg N will cost GH¢ 2.86. (MOFA, 2011).

Table 16. Dominance Analysis for local varieties, OPV and hybrids under three nitrogen levels at Kwadaso and Ejura in the major and minor seasons respectively.

Variety type	Total variable cost (GH¢)	Net benefit (GH¢)
0 kg N ha^{-1}		
Local varieties	0.00	1082.78
OPVs	40.00	1443.71
Hybrids	60.00	1622.70*
45 kg N ha^{-1}		
Local varieties	153.57	1056.03
OPVs	153.57	1602.29
Hybrids	213.57	2064.18
90 kg N ha^{-1}		
Local varieties	307.14	1638.94
OPVs	307.14	1882.81
Hybrids	367.14	2500.77**

* Good option for marginal rate of returns analysis

Marginal Rate of Returns (MRR)

Local variety (0 kg N ha^{-1}) – hybrids (0 kg N ha^{-1}) $= \frac{1622.70 - 1082.78}{60.00 - 0.00} \times 100$

= 899.87 %

Hybrids (0 kg N ha^{-1}) – hybrids (90 kg N ha^{-1}) $= \frac{2500.77 - 1622.70}{367.14 - 60.000} \times 100$

= 285.89%

CHAPTER 5

5.0 DISCUSSION

Genotypes were significantly different for grain yield because they were developed from different parental lines, belong to different maturity groups, are season specific and were developed individually to meet specific breeding objectives. Similar results and reasons were cited for genotypic differences in grain yield by Ewool (2004) and Sallah *et al*. (2004). Generally hybrids had higher yields than OPVs and local check varieties because traits related to yielding abilities in hybrids such as shorter ASI, longer cob length, and better resistance to root lodging were observed to be better in comparison with all other varietal groups. The observations made by Karunaratne (2001) that hybrid maize varieties generally have improved greatly in numerous agronomic traits resulting in their improved yielding abilities due to allelic differences at loci of the parents, leading to heterozygosity in hybrids and resultant expression of heterosis in the hybrids confirms the obtained results.

Significant genotype × environment interaction (GEI) has often been observed in multi-environmental maize yield trials in West and Central Africa (Badu-Apraku *et al*., 2003, 2007, 2008, 2009, 2010). GEI emanates from changes in the magnitude of response of cultivars to diverse growing conditions, when evaluated across years and locations (Mishra *et al*., 2006). GEI usually presents a problem for plant breeders because it causes uncertainty when translating the relative performance of cultivars in one environment to performance in a different environment. Consequently, prior to the release of cultivars, it is highly imperative to conduct multi-environmental yield trials so as to enable plant breeders identify and select high yielding cultivars with specific or broad adaptation to different agro-ecological zones. Furthermore, information obtained from such trials could aid national breeding programmes by recognizing suitable breeding materials with specific stress tolerance, desirable agronomic traits, and end-use quality attributes for utilization (Badu-Apraku *et al*., 2010). In the present study, highly significant genotype × nitrogen, genotype × location, and genotype × nitrogen × location interactions were found for grain yield.

In GEI analysis, one is concerned with identifying the best performing cultivar in a given environment and the most suitable environment for each cultivar, the average yield and stability of the genotypes and the discriminating ability and representativeness of the test environments. The GGE biplot methodology proposed by Yan *et al*. (2000) is a powerful statistical tool for performing the above-mentioned analyses with ease. In the current study, the "which won where" GGE biplot analysis revealed that 'Etubi' and 'Mamaba' were the highest yielding genotypes under no nitrogen and high nitrogen application respectively. This means that hybrids are more efficient in using nitrogen than OPVs and local varieties. Although root depth were not checked in this study, the good standability and low lodging in the hybrids could be indicative of deep root system that also made them efficient in nitrogen uptake. Similar reasons were assigned by Laffite and Edmeades (1994).

The reliability of a cultivar's performance across locations is an important consideration in plant breeding. Stability of a cultivar depends on its ability to perform similarly regardless of the productivity levels of environment; thus the cultivar is adapted to a broad range of environments. A cultivar's stability is also influenced by the genotype of the individual plant and the genetic relationship among plants of the cultivar (Fehr, 1987). 'Mamaba' and

‘Etubi’ were ranked as the genotypes that best combine high yielding abilities with stability across environments (nitrogen and location combinations). Thus under no and high nitrogen application (at both Ejura and Kwadaso), ‘Etubi’ and ‘Mamaba’ would produce better yields respectively. The result is supported by findings of Badu- Apraku *et al*. (2010) which emphasize the need for integrating stability of yield performance with mean yield to select high yielding genotypes. OPVs were high yielding than local varieties but were less stable whilst local varieties were highly stable but low yielding. Stability of local varieties confirm report by Odendo *et al*. (2001) that farmers prefer local varieties because they can be grown under stress conditions such as low rainfall and diseases as they serve as risk management strategy against environmental disaster. Yields of local varieties are however very low and are therefore not recommended.

Kwadaso under 90 kg N/ ha was the environment observed to be most representative of all test environment and had the highest discriminating ability for selecting superior genotypes. This means that in the selection of ideal genotypes this environment was the best.

Significant grain yield differences observed for the two locations (Ejura and Kwadaso) used in the present study could be attributed to differences in soil property and fertility levels in the forest and transitional agro-ecological zones. Also seasonal effects could account for grain yield differences at the two locations as the present study was conducted in different seasons of the same year for the two locations. Yields at Kwadaso were generally better than those recorded at Ejura for all genotypes because environment provided for maize growth at Kwadaso was nearer to an ideal maize growing environment. Soil at Kwadaso was more fertile than soil at Ejura for all nutrients tested before planting.

pH of soil at Kwadaso was also within the optimum requirement for maize growth (5.8-6.5) whiles soil at Ejura was more acidic with respect to the optimum recommendation. With respect to cropping history of the two experimental sites, field at Kwadaso had been subjected to continuous cropping under optimum fertilizer supply for several seasons whiles the Ejura experimental site had seen little nutrient replenishment. Sallah *et al*. (2004) also recorded significant location effect.

Significant nitrogen effect observed for grain yield, shelling percentage, cob diameter, and several other agronomic traits, is in agreement with those obtained by Alabi *et al*. (2003) who detected significant nitrogen effects for grain yield and other agronomic traits.

Significant interaction between genotypes, nitrogen and location for grain yield suggests the possibility of selecting ideal genotypes for specific nitrogen levels at Ejura and Kwadaso. These were due to the differences that existed in the locations involved and difference in response of genotypes to nitrogen supplied. Similar interactions were observed by Sallah *et al*. (2004).

Economic benefit analysis showed that net benefit associated with the cultivation of hybrid under 0 kg N ha^{-1} application (GH¢ 1622.70) at Kwadaso and Ejura was significantly higher than cultivation of local varieties under no nitrogen (GH¢ 1082.78). Hence cost associated with purchasing hybrid seeds seasonally warrant their cultivation since the net benefit is greater, with a marginal return of 899.87 %. It was also found that the cultivation of hybrid varieties under 90 kg N ha^{-1} produced net benefit of GH¢ 2500.80 with marginal return of 285.89% over the cultivation of same hybrid varieties with no application of nitrogen. It is therefore better to cultivate hybrids under 90 kg N ha^{-1}. Ewool (2004) however recommended the cultivation of hybrid under 45 kg N ha^{-1} as the best option for higher net benefit.

The current study has shown that the hybrids would require additional fertilizer inputs in order to realize their potential yield advantage. The pursuit of a green revolution in cereal production, particularly maize, in Ghana and the sub-region should therefore be directed towards the development of hybrids combined with the provision of fertilizers, as a package to farmers.

The studies also recorded significant correlation between grain yield and 1000 seed weight, days to mid anthesis, days to mid silking, ASI, cob aspects, cob length, ears per plant, grain length, grain width, plant height and shelling percentage. This means that plant breeders can use these traits as indicators in predicting yield. This is because when two traits are correlated, selecting for one would ensure selection for the other trait, thus selecting for the best of the above traits would result in improved yields. Negative correlation between grain yield and ASI was reported by Duvick (2005). Correlation between grain yield and plant height, cob diameter, cob diameter, cob length, 1000 seed weight and days to mid anthesis was also reported by Annapurna *et al*. (1998).

CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Three hybrid varieties, five OPVs, one local variety and four inbred lines were evaluated under three nitrogen levels in Kwadaso and Ejura to compare their relative yielding abilities and stability under low and high nitrogen.

Results showed that:

- Hybrid maize varieties had improved yielding abilities over OPVs and local varieties under both low and high nitrogen.
- ‘Etubi’ was the highest yielding genotype under low nitrogen whilst ‘Mamaba’ was the highest yielding under high nitrogen.
- Hybrid varieties were also able to effectively combine stability with their high yielding abilities under no and high nitrogen application.
- Correlation analysis also revealed that improvement in 1000 seed weight, days to mid anthesis, days to mid silking, ASI, cob aspects, cob length, ears per plant, grain length, grain width, plant height and shelling percentage has resulted in the improved yield observed in hybrids.
- Economic benefit analysis also showed that the best option for the highest net benefit in maize cultivation is the use of hybrid varieties under 90 kg N ha^{-1}. Net benefit was also higher in growing hybrids under low nitrogen than growing local varieties and improved OPVs under no nitrogen.

6.2 RECOMMENDATIONS

It is recommended that;

- Farmers should be encouraged to buy and use hybrid seeds to take advantage of their high yields under low nitrogen. For maximum benefit, the fertilizer subsidy policy by the government should be vigorously pursued and well managed to deliver hybrid seed and fertilizers to farmers at the right time.
- Secondly, large quantities of hybrid seeds should be produced by seed companies to bring down the unit price of hybrid seed, to make it affordable to farmers.

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