Studies on performance of some open-pollinated maize cultivars in the Guinea savanna. II. Genetic contribution to productivity of four cultivars under varying population and nitrogen regimes

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SUMMARY

Three late-maturing varieties of maize (*Zea mays* L.) released from 1972 to 1988 and one local cultivar were evaluated in replicated field trials at Nyankpala and Damongo in 1992 and 1993. Plant densities (30 000, 50 000, 70 000 plants ha^{-1}) were assigned to the main-plots and 12 combinations of N fertilizer levels (0, 80, 160 kg N ha^{-1}) and varieties (Local, Composite 4, Dobidi, Okomasa) were assigned to the sub-plots in four replicates. The objective was to determine the rate of increase in grain yield due to genetic improvement under the different levels of soil fertility and plant densities. Across location analysis for grain yield showed significant (P<0.05) differences among plant densities and highly significant (P<0.01) differences among nitrogen levels and varieties. The density x nitrogen and nitrogen x variety interactions were also significant. The overall variety mean grain yields were 3.08, 4.44, 4.48 and 4.60 t ha^{-1} for the local variety, Composite 4, Dobidi and Okomasa, respectively. 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. 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. The data showed that (i) significant progress has been made in genetic improvement of maize in Ghana since breeding programmes were initiated in the mid-1950s, (ii) breeding was effective in improving yield potential of maize under low as well as at high levels of soil fertility, (iii) increase in yield potential of the varieties resulted in corresponding increases in size and uniformity of ears, 1000-seed weight and tolerance to lodging, and (iv) increase in yield

RÉSUMÉ

SALLAH, P. Y. K., TWUMASI-AFRIYIE, S. & OBENG-ANTWI, K.: *Des études sur le rendement de quelques variétés de maïs de la pollinisation-exposée dans la Savane guinéenne. II. La contribution à la productivé, de quatre variétés sous la population variante et les régimes d' azote.* Trois variétés de maïs (*Zea mays* L.) de maturité tartive, fait sortit de 1972 à 1988 et une variété locale, étaient évaluées au cours des essais au champs réparti à Nyankpala et à Damongo en 1992 et en 1993. Les densités de plante (30 000, 50 000, 70 000 plante ha^{-1}) étaient assignées aux lots-principaux et 12 combinaisons des niveaux d'engrais N (0, 80, 160, kg N ha^{-1}) et les variétés (Locale, Composite 4, Dobidi, Okomasa) étaient assignées aux lots-secondaires en quatre replicatifs. Le but était de déterminer la proportion d'augmentation en rendement de graine dû à l'amélioration génétique sous les différentes niveaux de la fertilité du sol et les densités de plante. Une analyse, en travers d' emplacement pour le rendement de graine montrait des différences considérables (P<0.05) entre les densités de plante et des différence extrêmement considérable (P< 0.01) entre les niveaux d' azote et les variétés. Les intéractions de densité × azote et azote × variété étaient considérables. L'ensemble des rendements moyens de variété graines étaient 3.08, 4.44, 4.48 et 4.60 t ha^{-1} pour les variétés Locales, de Composite 4, Dobidi et respectivement d' Okomasa. Les estimation de régression linéaire des augmentation de rendement de graine (les gaines de rendements) par an étaient 32.3 kg ha^{-1} à N-zero, 45.1 kg ha^{-1} à 80 kg N ha^{-1} et 56.4 kg ha^{-1} à 160 kg N ha^{-1}. Les estimations linéaires à travers les trois niveaux de N étaient considérable et positive pour le rendement de graine, les jours jusqu' à 50 pour cent d' apparition de soie, le pourcentage du contenu d'humidité de graine à la moisson, et le poids de 1000-graines, maïs elle étaient négatives pour l'évaluation de l' acceptabilité d' épi et le pourcentage total d'abattage. Le poids de mille

Ghana Jnl agric. Sci. **31**, 153-160 | Accra: National Science & Technology Press

potential did not result in proportionate yield increases in farmers' fields.

Original scientific paper. Received 11 Jun 97; revised 27 Aug 98.

graines, le poids de fourrage et les épis par plante, avaient des corrélations positives considérables avec les rendement de graine alors que l'évaluation d'épi et l' abbattage total étaient négativement corrélés avec le rendement. Les données montraient que (i) un progrès considérable a été fait à l' amélioration génétique du maïs au Ghana de puis que les programmes de procréation étaient initiées pendant les années de mi-1950, (ii) la procreation était efficace à l'amélioration du potentiel de rendement du maïs à bas niveau ainsi qu' à haute niveau de la fertilité du sol, (iii) l'augmentation en potentiel de rendement des variétés aboutissait aux augmentations correspondantes de la dimension et d'uniformité des épis, le poids de 1000 - graines et la tolérance à l' abbattage, et (iv) l' augmentation en potentiel de rendement n' a pas abouti aux augmentation proportionelles de rendement dans les champs des cultivateurs.

Introduction

Yield performance of maize has improved in Ghana during the past three decades. Though reliable production figures are unavailable, it is estimated that maize grain production increased from 481,600 t in 1970 to 1 034 200 t in 1995 (PPMED, 1991; 1996). During the same period, average maize yields increased from 1.07 t ha^{-1} to 1.55 t ha^{-1} (PPMED, 1991; 1996). This increase in maize productivity can be attributed to genetic improvement of maize as well as to improved cultural and management practices adopted by maize growers in the country. However, the genetic contribution to this yield increase is unknown and needs to be determined.

Several studies have reported the genetic contribution to increased maize yields elsewhere (Carlone & Russell, 1987; Castleberry, Crum & Krull, 1984; Duvick, 1977; Russell, 1974). These authors reported that about 60 per cent of the increase in yield in the US Corn Belt could be attributed to genetic improvement. Genetic yield improvement was associated with improved resistance to lodging, ear droppage, and barrenness, besides to improved yield potential.

Maize is now an important cereal produced for direct human consumption in the Guinea savanna zone of Ghana. This was not so when maize-breeding research for the Guinea savanna zone of Ghana was initiated in the mid-1950s (Agble, 1981). J. McEwen, working in northern Ghana, released two improved early-maturing yellow varieties (Nyankariwana I and II) between 1954 and 1961. M. K. Akposoe, whilst with the Crops Research Institute, recommended the late varieties (Composite 4 and La Posta CRI) in 1972 for production in the Guinea savanna zone of Ghana (Agble, 1981). More recently, a team of breeders at the CRI released Dobidi and Okomasa, both late-maturing varieties (Sallah *et al.,* 1993; GGDP, 1988) which were widely grown in the northern savanna zone (GGDP, 1991).

Before the improved maize varieties were introduced, landrace cultivars, commonly called local maize varieties, were the type of varieties grown by farmers in the Guinea savanna. Evaluation of the local varieties along with the improved varieties developed and released in the different years should, therefore, permit an estimation of the genetic improvement of maize in the Guinea savanna zone of Ghana (Carlone & Russell, 1987; Mozingo, Coffelt & Wynne, 1987; Castleberry, Crum & Krull, 1984; Duvick, 1977; Russell, 1974).

Besides improved seed, improved cultural and management practices were developed and extended to farmers (GGDP, 1993). One such management practice was application of nitrogen

(N) in the form of organic and inorganic fertilizers. Removal of subsidies on agro-chemicals raised fertilizer prices beyond the reach of the resource-poor, small-scale farmers who are the major maize producers. Consequently, most farmers now rely on low soil residual N and, to a limited extent, on organic manures to grow maize. Information on genetic yield gains under these conditions would, therefore, guide breeders in choosing more efficient and relevant breeding strategies.

This study aimed to determine the rate of yield increase due to genetic improvement in maize varieties under varying levels of soil fertility.

Materials and methods

One local maize cultivar and three improved open-pollinated cultivars, namely Composite 4, Dobidi and Okomasa, all late-maturing varieties, were evaluated in the study (Table 1). The local variety was collected from a farmer close to the test site to represent the unimproved landrace variety grown by farmers in the area before improved cultivars were introduced. Composite 4, Dobidi and Okomasa were released for commercial production in 1972, 1984 and 1988, respectively (Agble, 1981; GGDP, 1988; Sallah *et al.*, 1993). Active maize improvement reseach was started in the mid-50s (Agble, 1981) and since only landrace were the varieties available then, 1955 was assumed as the year the local varieties were released for purposes of comparison.

The varieties were grown in 1992 and 1993 on an alfisol at Nyankpala (Lat. 9° 25' N, Long. 0° 58' W) and Damongo (Lat. 9° 05' N, Long. 1° 49' W) located in the Guinea savanna zone. The previous crop on the experimental fields in both years was cowpea (*Vigna unguiculata* L. Walp.). The experiment was a factorial in RCB design with three sets of treatments arranged in a split-plot with four replications. Plant densities (30 000, 50 000, 70 000 plants ha^{-1}) were randomized in the main plots and 12 treatment combinations of N levels (0, 80, 160 kg N ha^{-1}) and varieties (Local, Composite 4, Dobidi, Okomasa) were randomized in the sub-plots. All plots were disk-ploughed, harrowed once, and ridged before planting. Phosphorus and K were broadcast over all plots at 60 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1}, respectively, before harrowing.

The sub-plots consisted of four 5-m rows of each cultivar. Rows were spaced at 0.75 m. Three seeds were planted within the row at 0.88, 0.53 and 0.38 m to ensure the target densities of 30 000, 50 000, and 70 000 plants ha^{-1} were obtained after thinning. Pre-emergence chemical weed control was practised and consisted of application of a combination of Pendimethalin at 1.5 kg a.i. ha^{-1} and Gesaprim at 1.0 kg a.i. ha^{-1} at planting. Supplemental hoeing was also done when necessary to keep plots free of weeds. The N was

TABLE 1

Characteristics of Four Late-maturing Maize Cultivars Evaluated under Three Plant Densities and Three N Levels at Nyankpala and Damongo in 1993 and 1994

Cultivar	*Parental source*	*Grain type*	*Year released*	*Stated reason for release of variety*
Composite 4	CRI Pop.	White, dent	1972	High yield, tolerance to lodging
Dobidi	CIMMYT Pop. 43 (La Posta)	White, dent	1984	High yield, tolerance to lodging, improved husk cover
Okomasa	CIMMYT Pop. 43-SR (La Posta)	White, dent	1988	High yield, tolerance to lodging, MSV+; improved husk cover
Local	Landrace (Farmer)	Segregating	1955++	Low yield potential, segregating white, yellow, purple; flint

\+ Maize streak virus disease

++ Assumed to reflect the year active maize breeding was initiated in Ghana.

hand-applied as urea 10 days after planting.

Data were recorded on the two middle rows of each sub-plot for grain yield, days to 50 per cent silking, plant and ear heights, total lodging, grain moisture, ears per plant, ear rating, and for 1000-seed weight. Grain yield was expressed in kg ha^{-1} at 15 per cent grain moisture. Ears from each sub-plot were rated on a 1-5 scale, with 1 signifying good ear and 5 signifying poor ear, based on cob size, uniformity, and freedom from pest and disease attack.

Five cobs were chosen at random from each sub-plot to estimate 1000-seed weight at 15 per cent grain moisture. The MSTAT software was used to perform statistical analyses according to an RCB in split-plot arrangement across the two locations in 2 years. A mixed model was used, with environments (year-locations) being random; and varieties, densities, and N levels as fixed (Steel & Torrie, 1980). Linear regressions of mean grain yield and the other agronomic traits measured for the four varieties versus the year of release of the varieties were computed at each N level to determine the changes in the traits attributable to genetic improvement (Mozingo, Coffelt & Wynne, 1987).

Results

The growing seasons in both years had periods of intermittent moisture stress during the vegetative phase of the maize crop which affected general plant development. Drought after planting at Damongo in 1993 resulted in low plant establishment with adverse effects on the plant density and fertilizer N treatments.

Data from this environment (year-location) were, therefore excluded from the analyses because of their high variability.

Analyses of variance across the three environments for grain yield are not presented but showed significant (P<0.05) differences among plant densities, and also highly significant (P<0.01) differences among the N level and variety treatments (Sallah, Twumasi-Afriye & Frimpong-Manso, 1997). The densities × N levels and the varieties × N levels interactions were significant, but the varieties × densities and the varieties × densities × N levels interactions were not significant (Sallah, Twumasi-Afriye & Frimpong-Manso, 1997). The main density, N level, and variety effects and their interactions were discussed.

Since the N level × varieties interaction was significant for grain yield, the variety and N effects could not be interpreted independently (Sallah, Twumasi-Afriyie & Frimpong-Manso, 1997). Therefore, to determine the trends in yield changes due to breeding, mean grain yields across environments for the four varieties were plotted versus the year of release of the varieties at each level of applied fertilizer. The plots showed linear yield increases from 1955 to 1988 at all levels of applied fertilizer N (Fig. 1, 2, and 3).

Linear regression estimates indicated that the yield increase (yield gain) attributed to genetic improvement was 32.3 kg ha^{-1} yr^{-1} of grain at zero fertilizer N (Fig. 1), 45.1 kg ha^{-1} yr^{-1} at 80 kg N ha^{-1} (Fig. 2), and 56.4 kg ha^{-1} yr^{-1} at 160 kg N ha^{-1} (Fig. 3). The R^2 values associated with the linear regressions were 0.88, 0.81, and 0.86 at 0, 80, and 160 kg N ha^{-1}, respectively. The yield gain per year expressed as a proportion of the yield of the

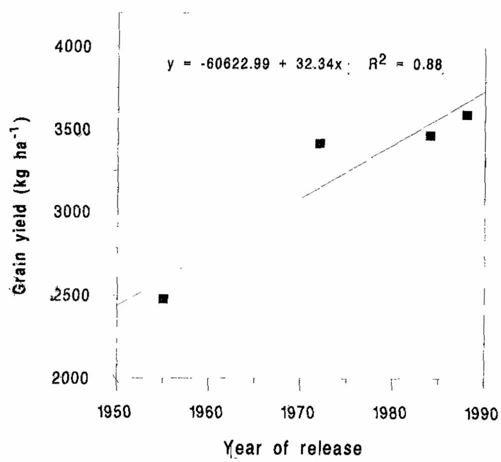

Fig. 1. Linear regression of grain yield of four maize varieties at zero applied N versus year of release of variety.

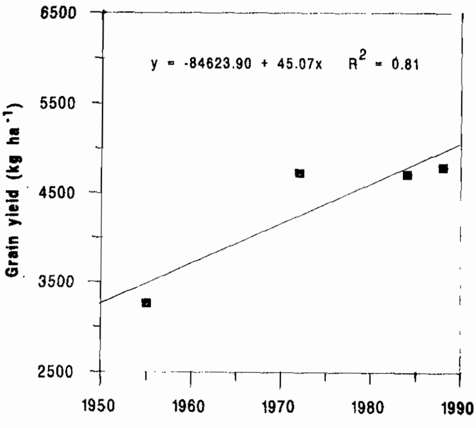

Fig. 2. Linear regression of grain yield of four maize varieties at 80 kg N ha^{-1} versus year of release of variety.

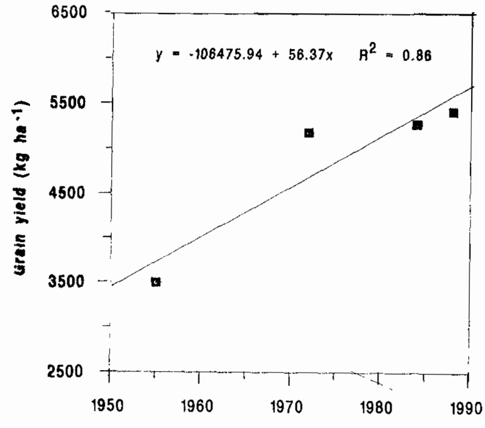

Fig. 3. Linear regression of grain yield of four maize varieties at 160 kg N ha^{-1} versus year of release of variety.

local variety at each level of fertilizer N was 1.3 per cent at 0-N, 1.4 per cent at 80 kg N ha^{-1}, and 1.7 per cent at 160 kg N ha^{-1}. The gains were similar for 0-N and 80 kg N ha^{-1}, but was slightly higher at 160 kg N ha^{-1}. These estimates showed that breeding was effective in improving the yield potential of maize under the different levels of fertilizer N application.

Table 2 shows the mean performance of the four varieties in the 10 agronomic traits measured over the three N levels along with the linear changes in these traits associated with genetic improvement. Differences among the varieties were significant for all the traits except number of

TABLE 2

Means for 10 Agronomic Traits of Four Maize Cultivars Averaged over Densities and N Levels and Linear Estimates due to Genetic Improvement

	Varieties					
Traits	*Local*	*Composite 4*	*Dobidi*	*Okomasa*	*SE*+	b_i¶
Grain yield (kg ha^{-1})	3080	4442	4483	4599	74	4 46
Mid-silk (days)	61.9	63.8	63.7	63.4	0.4	0.04
Plant height (cm)	187	206	185	183	2.5	NS
Ear height (cm)	94	113	92	90	1.9	NS
Grain moisture (%)	14.9	15.8	16.9	16.0	0.5	0.06
Ear rating++	2.8	2.7	2.5	2.6	0.09	-0.01
Ears per plant (no.)	0.93	0.95	0.92	0.94	NS	NS
Grain weight (g)	291	308	321	304	5.6	0.61
Stover weight (kg ha^{-1})	5399	5997	5779	5951	NS	NS
Total lodging (%)	35.2	27.5	23.8	22.9	1.9	-0.4

\+ Standard error

¶ Linear regression coefficient or linear change in value of trait due to genetic improvement

++ Ear acceptability rating, 1 = good ear and 5 = poor ear.

NS = not significant at 5 % probability level.

ears per plant and stover dry weight. The local variety yielded significantly lower than all improved varieties. The yield superiority of the improved varieties over the local variety was 44.2 per cent for Composite 4, 45.6 per cent for Dobidi, and 49.3 per cent for Okomasa (Table 2). Okomasa significantly out-yielded Composite 4 by 3.5 per cent. However, the yield differences between Composite 4 and Dobidi, and between Dobidi and Okomasa were not significant.

The local variety tended to silk earlier, lodged more severely, had a lower grain weight and grain moisture at harvest, and produced ears which were rated less acceptable than the improved varieties (Table 2). There was no significant difference between the local variety and Dobidi or Okomasa for plant height and ear placement. Composite 4 had the tallest plant type and ear placement above ground level (Table 2).

Significant linear changes due to genetic improvement were observed for grain yield, 50 per cent silk emergence, percent grain moisture, ear rating, grain weight, and total lodging (Table 2). Linear estimates were positive for yield, days to 50 per cent silking, grain moisture, and 1000 -grain (seed) weight, but were negative for ear acceptability rating and total lodging. Linear estimates for plant and ear heights, though positive, were not significant (Table 2).

Table 3 shows the simple correlation coeficients between grain yield and the other agronomic traits. These correlations were calculated from mean values of grain yield as the *y* variable, and means of the other traits as the *x* variable at the different variety × N level combinations. Ear rating, grain weight, ears per plant and total lodging had highly significant correlations with yield. Although stover dry weight and number of ears per plant did not differ among the varieties, both had significant correlations with grain yield. Ear rating and total lodging were negatively correlated with yield whereas grain weight, ears per plant and stover weight were positively correlated with yield. Ear height, mid-silk, and plant height showed the least relationship with grain yield.

TABLE 3

Phenotypic Correlations for Grain Yield with Nine Other Agronomic Traits of Four Maize Cultivars Evaluated at Nyankpala and Damongo in 1992 and 1993

Trait	*Correlation coefficient*
Mid-silk (days)	0.15
Plant height (cm)	0.23
Ear height (cm)	0.14
Grain moisture (%)	0.39
Ear rating (1-5 score)	-0.88 **
Thousand grain weight (g)	0.80 **
Ears per plant (no.)	0.77 **
Stover weight (kg ha^{-1})	0.58 *
Total lodging (%)	-0.89 **

Discussion

The varieties were evaluated at 0, 80, and 160 kg N ha^{-1} which represented low, intermediate, and high levels of soil fertility, respectively. Though the open-pollinated varieties were developed at the intermediate level of soil fertility, the yield gains attributed to genetic improvement were significant at all levels of soil fertility, and across the three levels of soil fertility. This showed that improved open-pollinated varieties have a greater yield potential than local maize varieties at low as well as at higher levels of soil fertility.

Significant gains were also made in improving the varieties for days to 50 per cent silking, percent grain moisture at harvest, ear acceptability rating, 1000 - grain weight, and percent total lodging. This was expected because these traits were subjected to intentional selection pressure along with selection for high yield potential in the breeding programmes. Highly significant correlations were also observed betweeen grain yield and weight, ear rating, and total lodging. The significant linear estimates and the high correlations with grain yield showed that genetic yield improvement was associated with increases in the size and uniformity of ears, grain weight, and tolerance to lodging.

Though breeding has been effective for improving the genetic potential of maize, critical examination of the yield data showed that yield was greatest with the replacement of the local variety with the first improved variety, Composite 4.

Thereafter, yield gains were relatively low, suggesting a yield plateau in the source populations from which the improved varieties were derived. Under this condition, further progress can only be expected if useful genetic variability for high-grain yield is introduced into the breeding populations. Alternatively, the development of highly productive and stable hybrids to replace the composites should be highly emphasized. A hybrid development programme is strongly advocated because much more progress is expected from this shift in emphasis, using the highly productive populations that have been developed as sources of parental inbred lines.

Genetic yield gains of 32.3 to 56.4 kg ha^{-1} yr^{-1} of gain observed in this study were low compared with gains reported in the US Corn Belt (Carlone & Russell, 1987; Castleberry, Crum & Krull, 1984; Duvick, 1977; Russell, 1974). This was expected because of differences between this study and the previous studies in the genetic materials as well as in the environments where they were evaluated. Entirely open-pollinated or composite varieties were used in the study, whereas the previous studies compared composites with hybrids which had higher yield potentials.

The yield gains observed in the Guinea savanna zone are probably typical of the gains that had been made in all the major maize-growing zones of Ghana. However, these gains did not seemingly cause proportionate yield increases in maize in farmers' fields (PPMED, 1991, 1996). The apparent lack of reliable estimates of maize yields in farmers' fields, which did not permit sound comparisons, partly accounted for this perception. Other reasons often given by farmers at annual planning workshops to explain the low yields on-farm included declining soil fertility coupled with high costs of inorganic fertilizers, obnoxious weeds including *Striga* spp. in the northern savanna zone, and drought stress.

Research efforts should aim to provide solutions to these problems to enhance the productivity of maize in resource-poor, small-scale farmers' fields. In addition, a favourable government policy is needed to promote the establishment of well-managed, medium- to large-scale farm enterprises to increase productivity of crops per unit area, increase incomes of farmers, provide the needed raw materials for the growing industrial sector, and to promote food security in the country.

Results from this study showed the following: (i) tremendous progress has been made in genetic improvement of maize in Ghana, since breeding programmes began three decades ago; (ii) breeding was effective in improving yield potential of maize under low as well as high levels of soil fertility; (iii) increase in yield potential of maize resulted in corresponding improvement in size and uniformity of ears, 1000-seed weight, and tolerance to lodging; and (iv) average maize yields in farmers' fields did not increase in proportion to genetic yield gains due to biotic and abiotic factors which limited productivity on-farm.

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