Studies on performance of some open-pollinated maize cultivars in the Guinea savanna. III. Nitrogen use efficiencies of four cultivars

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SUMMARY

Nitrogen use efficiency (NUE), defined as grain produced per unit of fertilizer nitrogen (N) applied, is a highly desirable agronomic character of non-leguminous crop varieties. This study was conducted to compare the NUEs of one local maize (*Zea mays* L.) variety and three improved composites released in Ghana since 1972, and determine the effects of breeding for improved agronomic performance on the NUEs of the improved cultivars. The four late-maturing maize cultivars (local, Composite 4, Dobidi, and Okomasa) were evaluated at 0, 80, and 160 kg N ha^{-1} and under three plant densities at Nyankpala and Damongo in 1992 and 1993. Across environment analysis for grain yield showed environment, plant density, nitrogen, and cultivar effects were significant ($P<0.05$). The environment × cultivar, environment × nitrogen, density × nitrogen, and nitrogen × cultivar interactions were also significant. Mean grain yields for the improved cultivars were 3.5, 4.7, and 5.3 t ha^{-1} at 0, 80, and 160 kg N ha^{-1}, respectively. Yields for the local variety were lower by 40.0, 42.2, and 51.4 per cent at 0, 80, and 160 kg N ha^{-1}, respectively. NUEs for the local variety, Composite 4, Dobidi, and Okomasa were 9.8, 16.4, 15.7, and 15.1 at 80 kg N ha^{-1}, and 6.4, 11.0, 11.3, and 11.4 at 160 kg N ha^{-1}, respectively. The NUEs over the two N levels were 8.1, 13.7, 13.5, and 13.1 for the four cultivars, respectively. NUE increased linearly at 0.15 yr^{-1} in improved cultivars over the local variety at both N levels. It was concluded that improved maize cultivars were more efficient in using fertilizer N than the local variety, NUEs did not differ among the improved cultivars, and that breeding resulted in 1.8 per cent yr^{-1} improvement in NUE over the local variety.

RÉSUMÉ

SALLAH, P.Y. K. & TWUMASI-AFRIYIE, S.: *Des études sur le rendement de quelques variétés de maïs de la pollinisation ouverte dans la savane guinéenne. II. Utilisation efficace d'azote de quatre variétés.* Utilisation efficace d'azote (U E A), défini comme le grain produit par unité d'engrais azoté (A) appliqué, est une caractéristique agronome hautement désirée des variétés de culture non-légumineuse. Cet étude s'est déroulée pour (1) comparer les UEAs d'une variété de maïs local (*Zea mays* L.) et trois composées améliorées introduites au Ghana depuis 1972 et (2) déterminer les effets de la reproduction pour un rendement agronomique amélioré sur les UEAs des variétés améliorées. Les quatre variétés de maïs de la maturité tardive (local, Composite 4, Dobidi, Okomasa) étaient évaluées à 0, 80 et 160 kg A ha^{-1} et sous trois densités de plante à Nyankpala et à Damongo en 1992 et 1993. Une analyse en travers de l'environnement pour le rendement de grain montrait que l'environnement, la densité de plante, l'azote et les effets de variétés étaient considérables ($P<0.05$). Les intéractions de l'environnement (×) variété, environnement (×) azote, densité (×) azote et azote (×) variété étaient également considérables. Les rendements moyens de grain pour les variétés améliorées étaient 3.5, 4.7 et 5.3 t ha^{-1} respectivement à 0, 80 et 160 kg A ha^{-1}. Les rendements pour la variété locale étaient plus bas par 40.0, 42.2, et 51.4 pour cent, respectivement, à 0, 80 et 160 kg A ha^{-1}. Les UEAs pour la variété locale, Composite, Dobidi, Okomasa étaient repectivement 9.8, 16.4, 15.7, 15.1 à 80 kg A ha^{-1} et 6.4, 11.0, 11.3, 11.4 à 160 kg A ha^{-1}. Les UEAs moyennes des deux niveaux d' A étaient 8.1, 13.7, 13.5, 13.1, respectivement, pour les quatre variétés. UEA augmentait linéairement à 0.15 par an, dans les variétés améliorées au-dessus de la variété locale à tous les deux niveaux d'A. La conclusion était tirée que (1) les variétés de maïs amélioré étaient plus efficace concernant utilisation d'engrais A que les variétés

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locales, (2) les UEAs n'étaient pas différentes parmi les variétés améliorées, (3) la reproduction aboutissait à une amélioration de 1.8 pour cent par an d'UEA audessus de la variété locale.

Introduction

Maize is a major cereal produced under rain-fed agriculture in the Guinea savanna zone of Ghana. Though the area planted to maize increased tremendously in the zone during the past two decades, maize yields are low in farmers' fields, averaging 1.4 t ha^{-1} (PPMED, 1996). One main reason for these low yields is that the soils are low in fertility, particularly nitrogen (N). Since the available N in these soils is low, application of inorganic or organic N fertilizer is recommended for maize production. Therefore, maize varieties that are efficient in using N fertilizers are desirable and need to be developed.

Nitrogen use efficiency (NUE) is defined as the maize grain produced per unit of applied fertilizer N (Moll, Kamprath & Jackson, 1982). Nitrogen use efficiency is determined by the ability of the genotype to accumulate soil and fertilizer N, and to use this N to produce the final grain yield (Beauchamp, Kannenberg & Hunter, 1976; Pollmer *et al.*, 1979). Nitrogen use (N uptake and translocation to developing grains) in maize is under polygenic control (Harvey, 1939; Pollmer *et al.*, 1979) and variation exists among maize genotypes for N utilization (Harvey, 1939; Chevalier & Schrader, 1977; Pollmer *et al.*, 1979).

Due to the high cost of N fertilizers, it would be more economical for maize producers to adopt high-yielding and N-efficient maize varieties. However, information is unavailable on the N use efficiencies of maize varieties grown in Ghana.

The objectives of this study were to determine the N use efficiencies of four maize composites, representing one local and three improved cultivars released in Ghana since 1972; and to determine the effects of breeding on the N use efficiencies of the improved cultivars.

Materials and methods

One local maize variety and three improved cultivars, namely Composite 4, Dobidi and Okomasa, all late-maturing, were evaluated in the study (Table 1). The local variety was collected from the farmer close to the test site to represent the unimproved landrace variety grown by farmers in the area. Composite 4, Dobidi, and Okomasa were released, by CRI for commercial production in 1972, 1984 and 1988, respectively (Agble, 1981; GGDP, 1988; Sallah *et al.*, 1993).

The varieties were grown in 1992 and 1993 on an alfisol at Nyankpala (Lat. 09° 25' 41" N, Long. 0° 58' 42" W) and Damongo (Lat. 9° 04' N, Long. 01° 49' W) located in the Guinea savanna zone of Ghana. The previous crop of the experimental fields in each year at both sites was cowpea (*Vigna unguiculata* (L.) Walp.). Some physical and chemical characteristics of the soils were provided by Sallah *et al.* (1997). The field was disc-ploughed and harrowed once. Phosphorus and

TABLE 1

Characteristics of Four Late Maturing Maize Cultivars Evaluated at Nyankpala and Damongo in 1992 and 1993

Variety	*Origin*	*Grain type*	*Year released*	*Maize streak virus*$^{+}$
Composite 4	CRI	White, dent	1972	S
Dobidi	CRI	White, dent	1983	S
Okomasa	CRI	White, dent	1988	R
Local	Farmer	Segregating white, yellow purple, flint	1955^{++}	S

+ S = susceptible and R = resistance reaction to maize streak virus disease (MSV).

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

K were applied to all plots by hand-spreading at 60 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1}, and the plots were then ridged before planting.

The experiment was an RCB design with three sets of treatments in a split-plot arrangement with four replications per site. Plant densities (30 000, 50 000, 70 000 plants ha^{-1}) were randomized in the main plots and the N level (0, 80, 160 kg N ha^{-1}) × cultivar (local, Composite 4, Dobidi, Okomasa) treatments were randomized in the sub-plots. All the N was applied by spot-placement as urea 10 days after planting. The sub-plots were four 5-m rows spaced 0.75 m and hills within the row were properly spaced to give the desired plant density after thinning. Pre-emergence herbicide weed control was practised, but supplemental hoeing was also done when necessary to keep plots free of weeds.

Data were recorded on the two middle rows of a sub-plot for grain yield, days to 50 per cent silking, plant and ear heights (cm), total lodging (percent), number of ears per plant, ear acceptability rating, 1000-grain weight, percent grain moisture at harvest, and stover dry weight. Grain yield was expressed in kg ha^{-1} at 15 per cent grain moisture. Ear acceptability was rated on a 1 (very good) to 5 (very poor) scale based on size and uniformity of ears, ear filling, and freedom from pests and diseases. Five cobs were chosen at random from each sub-plot to estimate 1000-seed weight at 15 per cent grain moisture. The data were statistically analysed according to split-plot arrangement across the two locations in 2 years using MSTAT software. A mixed model was used with environments (year-locations) being random; varieties, densities, and N levels as fixed (Steel & Torrie, 1980). Nitrogen use efficiency was calculated as the increase in yield (kg ha^{-1}) divided by the quantity (kg ha^{-1}) of fertilizer N applied from zero applied fertilizer N (0-N) to 80 kg N ha^{-1} (80 - N), 0-N to 160 kg N ha^{-1} (160-N), across the two N levels, and from 80-N to 160-N. Genetic improvement in NUE of the varieties at each N level was estimated as the linear regression of NUE versus year of release of the varieties (Mozingo, Coffelt & Wynne, 1987).

Results and discussion

Severe moisture stress after planting at Damongo in 1993 resulted in poor plant establishment which adversely affected the plant density and N fertilizer treatments. Data from this environment were, therefore, excluded from the analyses.

The analyses of variance across the three environments for grain yield are not presented, but showed significant (P<0.05) differences among plant densities and highly significant (P<0.01) differences among N levels and cultivars. The environment × cultivar interaction was highly significant (P<0.01), the N level × cultivar interaction was significant (P<0.05), but the density × cultivar interaction was not significant. The main density, N fertilizer and cultivar effects, and their interactions have been thoroughly discussed (Sallah *et al.*, 1997).

The significant N level × cultivar interaction showed that the N response was affected by the type of variety. Table 2 shows mean grain yields across the three environments for the four cultivars at the three N levels. Grain yields at 0-N were relatively high, averaging 3.2 t ha^{-1} over all cultivars across the three environments (Table 2). The relatively high yields observed at 0-N were attributed to N contributions to the soils in the

TABLE 2

Mean Grain Yields of Four Late Maize Cultivars Evaluated Under Three N Fertilizer Levels in Three Environments in the Guinea Savanna Zone of Ghana

	N level (kg N ha^{-1})			
Variety	*0*	*80*	*160*	*Mean*
Local variety	2477	3264	3498	3080
Composite 4	3416	4730	5181	4442
Dobidi	3462	4715	5274	4483
Okomasa	3592	4796	5410	4599
Mean	3237	4377	4841	4152

Standard errors: Variety means = 73.7
Variety × N means = 127.7
Nitrogen means = 63.8

experimental fields by the preceding leguminous crops through biological N fixation (Sallah *et al.*, 1997).

The improved cultivars significantly out-yielded the local variety by 37.9-45.0 per cent at 0-N, by 44.5-46.9 per cent at 80-N, and by 48.1-54.7 per cent at 160-N (Table 2). These observations implied that the improved cultivars were more productive than the local variety under low as well as under high levels of soil fertility. Yield differences among the improved cultivars were not significant at all levels of fertilizer N application (Table 2), indicating that improved cultivars of all ages showed similar yield responses to applied N.

Fig. 1-4 illustrate estimates of nitrogen use efficiencies (NUEs) for the four cultivars. Nitrogen use efficiencies at 80-N were 9.8, 16.4, 15.7, and 15.1 for the local variety, Composite 4, Dobidi and Okomasa, respectively (Fig. 1). These figures showed the amount of grain (yield) that was produced by each variety for every unit of the 80 kg N ha^{-1} applied. For example, the local variety produced 9.8 kg grain per kilogram of fertilizer N whereas Okomasa produced 15.1 kg grain per kg N at the 80 kg N ha^{-1} rate. At 160-N, the NUE was 6.4 for the local variety, 11.0 for Composite 4, 11.3 for Dobidi, and 11.4 for Okomasa (Fig. 2). Nitrogen use efficiencies averaged over the two N levels were 8.1, 13.7, 13.5, and 13.1 for the local variety, Composite 4, Dobidi, and Okomasa, respectively (Fig. 3). These results showed that improved varieties were more efficient in using applied N for grain production than the local variety at the 80 and 160 kg N ha^{-1} levels. Fig. 4 illustrates nitrogen use efficiencies of the four varieties from 80-N to 160-N. It showed that NUE was lowest for the local variety and increased progressively for Composite 4, Dobidi, and Okomasa. This

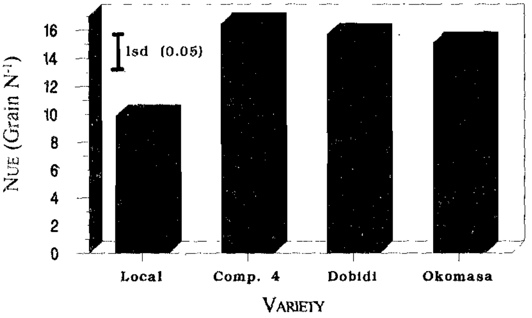

Fig. 1. Nitrogen use efficiencies of four open-pollinated maize varieties estimated from 0 to 80 kg ha^{-1} applied fertilizer N in the Guinea savanna zone of Ghana.

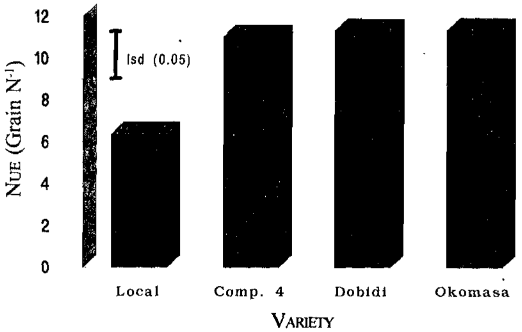

Fig. 2. Nitrogen use efficiencies of four open-pollinated maize varieties estimated from 0 to 160 kg ha^{-1} applied fertilizer N in the Guinea savanna zone of Ghana.

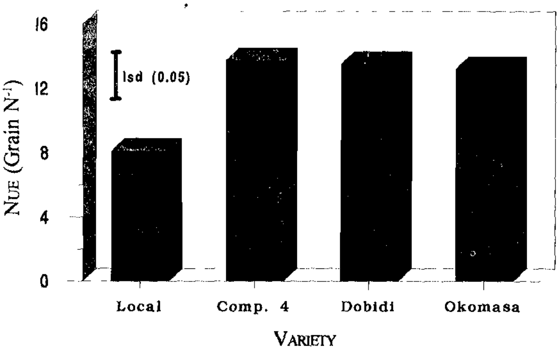

Fig. 3. Nitrogen use efficiencies of four open-pollinated maize varieties across 80 and 160 kg ha^{-1} applied fertilizer N in the Guinea savanna zone of Ghana.

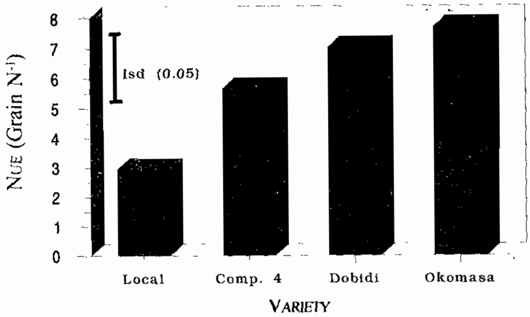

Fig. 4. Nitrogen use efficiencies of four open-pollinated maize varieties estimated from 80 to 160 kg ha^{-1} applied fertilizer N in the Guinea savanna zone of Ghana.

observation implied that after the initial application of 80 kg N ha^{-1}, the improved varieties were progressively more efficient in using the additional N supplied for grain production. However, maize growers rarely benefit from the improved N use efficiency at high N levels because farmers are unable to apply such rates.

The lack of significant differences among the improved varieties for nitrogen use efficiency at lower N rates might be attributed to the common N fertilization regime (90 kg N ha^{-1}) used during the development of these varieties. It is, therefore, important that selection for NUE be emphasized in maize-breeding programmes to evolve varieties that are more N-efficient at lower levels of N application.

Genetic variation for nitrogen use has been observed in maize germplasm (Harvey, 1939; Chevalier & Schrader, 1977; Pollmer *et al.*, 1979). However, prolific (showing multiple-ear character) maize germplasm might be more appropriate for the development of high-yielding, N-efficient hybrids (Moll, Kamprath & Jackson, 1987). In developing the N-efficient hybrids, selection for yield *per se* at a single N level, or averaged over high and low N rates was not as effective as selection for NUE (Moll *et al.*, 1987). Hence, choice of appropriate germplasm and selection criterion would be essential for significant progress in breeding for NUE in maize.

Linear regression estimates of NUE versus year of release of each cultivar were computed to determine the effects of breeding on the NUE of the improved cultivars at 80-N, 160-N, across the two N levels, and from 80-N to 160-N. Linear regression coefficients were 0.16 (R^2 = 0.62) at 80-N, 0.15 (R^2 = 0.84) at 160-N, 0.16 (R^2 = 0.73) across the two N levels, and 0.14 (R^2 = 0.99) from 80-N to 160-N (Table 3). Linear estimates were similar among the different N levels. These linear increases showed that breeding for increased yield potential resulted, on the average, in 1.8 per cent yr^{-1} improvement in NUE of improved maize cultivars over the local variety in the Guinea savanna zone.

TABLE 3

Estimates of Linear Increases in Nitrogen Use Efficiencies per Year in Maize Cultivars in Ghana Due to Genetic Improvement

N treatment	b_j^+	R^2
80 kg N ha^{-1}	0.159*	0.62
160 kg N ha^{-1}	0.150*	0.84
Across N levels	0.155*	0.73
80 - 160 kg N ha^{-1}	0.141**	0.99

+ Linear increases (regression coefficients) of NUE versus year of release of variety.

Table 4 shows the mean values for the other agronomic characters for each cultivar averaged over densities and N levels. Highly significant differences were observed among the cultivars for all characters except number of ears per plant and stover dry weight. These significant differences were due mainly to differences between the local variety and the improved cultivars. The local variety flowered a little earlier than the improved cultivars. Dobidi was similar to Okomasa in all characters except for its higher seed weight. Composite 4 had the tallest plant-type and highest ear placement above ground, but was similar to the other improved varieties in

TABLE 4

Means for Nine Plant and Ear Traits of Four Maize Varieties Averaged Over Densities and N Levels

Traits	*Varieties* *Local*	*Comp.4*	*Dobidi*	*Okomasa*	*SE*$^+$
Mid-silk (days)	61.9	63.8	63.7	63.4	0.4
Plant height (cm)	187	206	185	183	2.5
Ear height (cm)	94	113	92	90	1.9
Grain moisture (%)	14.9	15.8	16.9	16.0	0.5
Ear rating ++	2.8	2.7	2.5	2.6	0.09
Ears per plant	0.93	0.95	0.92	0.94	ns
Grain weight (g)	291	308	321	304	5.6
Stover weight (kg ha^{-1})	5399	5997	5779	5951	ns
Total lodging (%)	35.2	27.5	23.8	22.9	1.9

\+ = standard error

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

ns = not significant at 5 per cent probability level.

most other characters. In general, the local variety was more susceptible to lodging, had lower grain weight and ear acceptability rating than the improved cultivars.

Table 5 presents the simple correlation coefficients between NUE and 10 agronomic characters measured. Days to mid-silk and grain moisture at harvest were the only characters that showed significant positive correlations with NUE. Though not significant, correlations for grain yield and seed weight with NUE were positive whereas they were negative for ear rating, ears per plant, stover dry weight, and total lodging. Ear height, plant height, ears per plant, and stover dry weight showed the least relationship with NUE.

TABLE 5

Phenotypic Correlations for Nitrogen Use Efficiency (NUE) with 10 Agronomic Traits of Four Maize Varieties at 80 and 160 kg N ha^{-1}

Traits	*Correlation coefficient*
Grain yield (kg ha^{-1})	0.48
Mid-silk (days)	0.68*
Plant height (cm)	0.16
Ear height (cm)	0.16
Grain moisture (%)	0.81**
Ear rating (1-5 score)	-0.23
1000-grain weight (g)	0.39
Ears per plant (no.)	-0.11
Stover weight (kg ha^{-1})	-0.18
Total lodging (%)	-0.60

It was concluded from the study that improved maize cultivars released from 1972 to 1988 were more efficient in using applied fertilizer N for grain production than the local maize variety, the difference among the improved cultivars in NUE was very small, breeding for increased yield potential resulted in 1.8 per cent yr^{-1} increase in NUE in the improved cultivars over the local variety, and that selection for improved NUE needs emphasis in the breeding programme.

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