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RELATIONSHIP OF PLANT DENSITY AND NITROGEN FERTILIZATION TO MAIZE PERFORMANCE IN THE SOUTHERN GUINEA SAVANNA OF NIGERIA

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ABSTRACT

Experiments were conducted for three years (1975 - 1977) at Mokwa and Omu-Aran, in the southern Guinea savanna zone of Nigeria, to evaluate the response of maize (*Zea mays* L.) to five rates of N (0, 50, 100, 150 and 200 kg/ha) and three plant population densities (24, 48 and 72 thousand plants/ha).

Maximum grain yield was obtained with 120 kg N/ha and a population density of 50 000 plants/ha. There was a significant nitrogen × plant density interaction at both locations. Nitrogen-use efficiency, calculated as kg of grain per kg of fertilizer N, was highest at a population density of 50 000 and lowest at 24 000 plants/ha.

INTRODUCTION

The increasing demand for grains to feed the growing human population and the ever expanding livestock industries in Nigeria has created the need for the expansion of maize (*Zea mays* L.) cultivation to areas where it has not hitherto been extensively grown. The Guinea savanna ecological zone has been reported to have the greatest potential for maize cultivation in this country (Kassam and Kowal, 1973). Two of the factors which have been attributed to the limited cultivation of maize in this zone are the low levels of organic matter (Jones, 1973) and native phosphorus (Bache and Rogers, 1970; Mokwunye, 1974) of most savanna soils.

Maize is a relatively high-demanding crop and the relatively low soil fertility has rendered it impossible for maize to compete favourably with either millet or sorghum, both of which yield reasonably well under the sub-optimal fertility levels usually recorded in this ecological zone. The enormous potential of savanna areas for maize cultivation can therefore only be realized with high levels of fertilizer inputs, in addition to good management, optimum plant density and adequate weed control (Norman *et al.*, 1976).

Nitrogen is the main limiting nutrient in the savanna areas (Stockinger, 1966). Balasubramanian *et al.* (1978) observed that the maize crop failed to produce worthwhile grains without nitrogen fertilization. Goldsworthy (1967) reported response of maize to nitrogen fertilization and recommended a rate of 65 kg N/ha for maximum yield response throughout the savanna areas. Since the introduction of the high-yielding maize varieties, higher rates of nitrogen have, however, been observed to be necessary for maximum grain production in this ecological zone (Jones, 1974; Balasubramanian *et al.*, 1978; Ologunde and Ogunlela, 1982).

With better fertilization, soil management and adequate supply of moisture, high plant

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TABLE 1 Soil chemical analysis of the experimental sites prior to application of fertilizers

Property	Omu-Aran		Mokwa	
	1975	1976	1976	1977
pH (water)	6.1	6.3	6.5	6.5
Organic matter (%)	0.72	0.69	0.66	0.68
Total nitrogen (%)	0.05	0.03	0.03	0.04
Available P (ppm)	11.68	12.92	10.90	12.25
Exchangeable K (meg/100g)	0.17	0.15	0.15	0.11
CEC (meg/100g)	4.5	3.4	3.2	3.0

density has been found necessary to provide the number of plants required for maximum grain yield. When the plant density falls far below the optimum level, all other inputs of production fail to produce any appreciable effect on yield. The results of earlier maize trials conducted at Mokwa (de Wolff, 1968) indicated that a plant population density of 36 000 plant/ha would be adequate for maximum grain yield. However, with the release of some new cultivars, which are shorter in height and more responsive to fertilizer application, the present officially recommended plant population density of 36 000 plants/ha appears to be inadequate for maximum grain production. There is a need to determine the optimum combination of nitrogen fertilization and plant density for maize production in the southern Guinea savanna. Trials were therefore conducted at two locations to determine yield response of maize to nitrogen rates and plant population densities in this ecological zone.

MATERIALS AND METHODS

Field experiments were conducted in the 1976 and 1977 wet seasons at the Agricultural Research Station, Mokwa (9°18'N; 5°04'E) and in 1975 and 1976 at the Farm Centre in Omu-Aran (8°09'N; 5°06'E). Soil samples were collected from both sites at a depth of 0-20cm prior to fertilizer applications. Soil pH (1 : 1, soil : water) was determined using a Coleman pH meter. Total N and organic carbon were determined by standard procedures (Black, 1965). Relevant soil chemical analyses of the sites are summarized in Table 1, while the rainfall figures for Mokwa during the 1976-77 growing seasons are shown in Table 2. During the seedbed preparation, the experimental plot received a basal application of 60 kg each of P_2O_5 and K_2O/ha as single superphosphate and muriate of potash, respectively.

Treatments consisted of five rates of nitrogen (N) (0, 50, 100, 150 and 200 kg/ha) applied as calcium ammonium nitrate (26% N) and three plant population densities (24, 48 and 72 thousand plants/ha). Each rate of N was applied in two-split doses, half at sowing and half six weeks later. The sowing-time application was broadcast and incorporated in the soil together with the single superphosphate and the muriate of potash. The other half of N was placed as a

TABLE 2 Rainfall amounts (mm) in 5-day totals at Mokwa during 1976-77 growing seasons

Month	days	1976	1977
May	1-5	12.5	49.5
	6-10	28.5	58.4
	11-15	0.5	0.0
	16-20	4.3	19.3
	21-25	102.4	45.5
	26-31	76.0	49.5
	Total	224.0	222.3
June	1-5	69.9	94.5
	6-10	0.0	30.0
	11-15	42.7	30.7
	16-20	73.2	28.7
	21-25	10.2	42.9
	26-30	5.8	0.0
	Total	201.7	226.8
July	1-5	25.4	6.6
	6-10	4.3	1.3
	11-15	50.8	0.0
	16-20	4.1	53.5
	21-25	19.1	93.5
	26-31	7.6	19.3
	Total	111.3	174.5
August	1-5	0.0	0.0
	6-10	18.0	10.9
	11-15	15.8	23.6
	16-20	18.2	41.4
	21-25	15.2	3.3
	26-31	26.7	3.8
	Total	94.2	83.1
Total rainfall at sowing		102.6	112.5
Total effective rainfall		723.6	819.1

side-dressing about 8cm deep and 8-10cm away from the seedlings and covered with soil. The fifteen treatment combinations were laid out in a randomised complete block design with four replications. Each gross plot was 7.3 x 5.5m and the net plot, from which grain yield was estimated, was 5.5 x 3.6m

Two or four kernels of maize (cv. N.C.A.) were sown in the flat bed at 91cm inter-row spacing using two different intra-row spacings to obtain the desired plant density. For the 24 000 plants/ha, two kernels were sown and the stands were spaced 45cm apart within the rows; later they were thinned to one plant per stand. For the 48 000 and 72 000 plants/ha, four kernels were sown at intra-row spacings of 45 and 30cm, respectively, and thinned to two plants per stand two weeks later. Maize was sown at Mokwa on 4 May in 1976 and 9 May in 1977 and at Omu-Aran on 19 April in 1975 and 7 May in 1976.

Cobs were harvested at maturity and sun dried. Samples of 20 ears per plot, from which the yield components were estimated, were randomly selected. Grain yields were corrected to 12% moisture content. Yield components, measured only at Mokwa, included number of kernels per ear, 1000-kernel weight, number of ears per plant and shelling percentage. Other variables measured were days to 50% tasselling and 50% silking. Each of these variables was subjected to an analysis of variance. The observed values were further used to develop response surfaces using multiple regression techniques. The following equation was used as the model:

$$Y = b_0 + b_1N + b_2D + b_3N^2 + b_4D^2 + b_5ND$$

In this equation Y is the predicted value; N and D refer to actual quantities of N and plant density, respectively. The b values are the computed regression coefficients indicating linear, quadratic, or interaction effects of applied N and population density.

RESULTS AND DISCUSSION

Grain yield

Mean grain yields over the two years at both locations were essentially the same (Table 3). Yield increases of 83% and 33% were observed in 1977 over 1976 at Mokwa and in 1976 over 1975 at Omu-Aran, respectively. The total effective season's rainfall at Mokwa was slightly higher in 1977 compared with 1976 (Table 2). In addition, the sub-optimal rainfall distribution during the period between pre-tasselling and immediately following silking (25 June - 20 July) in 1976 could partly explain the lower grain yield recorded at Mokwa in that year. The rainfall for the month of July, when kernel development was taking place, was 111 and 175mm in 1976 and 1977, respectively.

Regression coefficients representing the effects of applied N and plant population on grain yield are shown in Table 4. There was a curvilinear response to applied N at the two locations in each year. Significant nitrogen x plant population density effects were observed at both locations. If, however, the data over the two years and population are combined the relationship between yield (kg/ha) and rate of fertilizer N (kg/ha) is given by the functions

$$Y = 2360.1 + 47.11\,N - 0.183N^2 \text{ at Mokwa and}$$
$$Y = 2049.7 + 41.63\,N - 0.163N^2 \text{ at Omu-Aran.}$$

Equating each of these derivatives to zero and solving for N resulted in optimum rates of 129 and 128 kg N/ha at Mokwa and Omu-Aran, respectively. These optimum rates are considerably higher than those reported by Stockinger (1966) and Goldsworthy (1967) who recommended an optimum rate of 65 kg N/ha in the savanna ecological zone. The response of maize to applied N observed in Mokwa and Omu-Aran was attributable mainly to the low soil organic matter contents and thus low N reserve in the soils of the two locations (Table 1). Jenny (1930) observed a positive correlation between maize yields and the total N content of soils at Missouri in the United States of America. The much higher response observed in this study as compared with those of Stockinger (1966) and Goldsworthy (1967) may be attributed partly to the degree of soil degradation but mainly to the use of an improved maize variety. In Ghana, under conditions resembling those of northern Nigeria, Nye (1951a, 1951b) found that the response of cereals to nitrogen and phosphorus was partly dependent on the cropping history of the land. Balasubramanian *et al.* (1978) suggested that to realize the full potential of new high-yielding and fertilizer-responsive maize varieties, it might be necessary to increase the rates of the major fertilizer elements. They recommended that 120-140 kg N/ha be applied to maize along with other major elements.

Nitrogen x year interaction was significant at Mokwa alone .(Table 5). Seasonal variations in grain yield of maize could be attributed to changes in weather conditions, especially rainfall, as explained earlier, during the growing seasons in whch the experiments were conducted. The rainfall distribution at Mokwa was generally better in 1977 than in 1976 (Table 2). Using the equations implied in Table 4 the optimum applied N required for maximum grain yield of 5500 kg/ha in 1976 (Table 5) was 141 kg/ha while the optimum rate required for maximum grain yield of 7130 kg/ha in 1977 was 129 kg N/ha. The lower N-use efficiency

TABLE 3 Mean grain yield and yield components of maize at two locations in the southern Guinea savanna of Nigeria, 1975-1977

	Omu-Aran	Mokwa	Mokwa				
	Grain yield (kg/ha)		No. of grains per ear	1000-kernel weight (g)	No. of ears per plant	Days to 50% tasselling	Shelling %
1975	3207	—	—	—	—	—	—
1976	4279	2606	399	312	1.00	64	80.6
1977	—	4768	388	248	0.98	61	80.8
Mean	3743	3687	394	280	0.99	63	80.7
L.S.D. (5%)	205**	217**	11*	8*	NS	0.7**	NS
C.V. (%)	15	16	8	8	15.0	3	4.4

* ** Significant at the 0.05 and 0.01 confidence levels respectively
N.S. Not significantly different at 5% probability level or less.

TABLE 4 The effect of applied N and plant density on grain production (kg/ha) of maize at two locations in the southern Guinea savanna of Nigeria, 1975—1977

Regression coefficient	Omu-Aran 1975	Omu-Aran 1976	Mokwa 1976	Mokwa 1977
Intercept	—1776.2	—3423.9	829.0	—3284.0
b_1 (N)	32.6**	48.9**	24.0**	49.7**
b_2 (D)	0.172**	0.255**	0.679**	0.275**
b_3 (N^2)	—0.155**	—0.175**	—0.138**	—0.227**
b_4 $(D)^2$	-0.2×10^{-5}**	-0.2×10^{-5}**	-0.7×10^{-6}*	-0.3×10^{-5}**
b_5 (ND)	0.1×10^{-3}*	-0.9×10^{-4}	0.3×10^{-3}**	0.2×10^{-3}*
R^2	0.801	0.768	0.836	0.823

* ** Significant at the 0.05 and 0.01 confidence levels, respectively

in 1976 as compared with 1977 is partly attributable to the over 69mm of rainfall recorded immediately after N application on 20 June (Table 2) in 1976 which probably washed off part of the applied N and thus made that fraction of applied N unavailable to the crop. Based on the data in Tables 4 and 5, it is apparent that the optimum N rate for maize at Mokwa and Omu-Aran lies between 100 and 150 kg/ha, with yield depression occurring beyond the 150 kg N/ha rate. There is therefore need to revise the nitrogen recommendation for maize in the southern Guinea savanna from the present 65 kg N/ha to 120 kg N/ha in order to allow for the greater N requirements of the improved higher-yielding varieties now grown.

Grain yield responded curvilinearly to increases in plant density at both locations (Table 4). Averaged over years and N rates, increases in grain yields were 45% and 53% when plant density was increased from 24 000 to 48 000 plants/ha at Mokwa and Omu-Aran respectively (Table 6). A further increase in plant density to 72 000 plants/ha resulted in 10% and 18% yield reductions at the respective locations. This result was expected since it is known that grain yields increase with increasing plant density up to a certain maximum beyond which any further plant density increase results in yield depression. Duncan (1954) reported that grain yield per maize plant decreased logarithmically as plant population density increased above the optimum level. Such a yield decline has been attributed, in part, to the reduction in the incident light within the lower strata of the maize canopy. The higher the population density the more leaves produced and the greater the leaf area index (LAI). Nunez and Kamprath (1969) and Hunter *et al.* (1970) observed that total LAI increased linearly with increase in population density from 34 500 to 69 000 plants/ha after which LAI per plant would start to decrease. At this point, the lowest leaves of the canopy would be so poorly illuminated that respiration would exceed photosynthesis, resulting in a reduction in grain yield. Other reasons given for the decrease in yield with mounting plant density include inter-plant competition for moisture, nutrients and carbon dioxide. Averaged over years, the calculated optimum plant densities at Mokwa and Omu-Aran were 52 000 plants/ha and 51 000 plants/ha, respectively. A density x year interaction was, however, observed at Mokwa where the optimum plant density required for maximum grain yield was higher in 1976 than in 1977 (Table 4).

A significant nitrogen x density interaction effect was observed during the two years at Mokwa but only in 1975 at Omu-Aran (Table 4). The average of the two seasons, however, indicated a significant nitrogen x density effect at both locations. If the data from the two years are combined, the relationship between grain yield (kg/ha), rate of fertilizer N and plant population density (D) is given by

$$Y = -1227.5 + 36.82N + 0.171D - 0.182N^2 - 0.000002D^2 + 0.00021ND \quad (R^2 = 0.705)$$

at Mokwa and

$$Y = -2600.1 + 40.78N + 0.211D - 0.170N^2 - 0.000002D^2 + 0.000002ND \quad (R^2 = 0.806)$$

at Omu-Aran

This equation giving the relationship between the three variables is depicted graphically in Fig. 1. The maximum grain yield was obtained with a combination of about 133 kg N/ha and 54 000 plants/ha at Mokwa. The corresponding values at Omu-Aran were 120 kg N/ha and 53 000 plants/ha. The relationships between grain yield (kg/ha) and applied N (kg/ha) for each of the three population densities at both locations are given by the response functions

TABLE 5 Response of maize grain yield to applied nitrogen in the southern Guinea savanna of Nigeria, 1975-1977

Treatment (kg N/ha)	Grain Yield (kg/ha)			
	Omu-Aran		Mokwa	
	1975	1976	1976	1977
0	1660.0	2505.5	1579.8	2490.3
50	3195.5	4021.4	2487.6	4519.3
100	3950.8	5546.5	3018.0	5926.2
150	4038.0	4886.6	3244.0	6119.1
200	3191.4	4438.4	2698.0	4787.0
Means	3207.1	4279.1	2605.5	4768.4
L.S.D. (.05) Nitrogen	387.0**	502.4**	250.0**	549.9**
Year	195.9**		216.7**	
Nitrogen x Year	N.S.		484.5**	

* ** Significant at the 0.05 and 0.01 confidence levels, respectively.
N.S. Not significantly different at 0.05 confidence level.

TABLE 6 Response functions showing the effect of applied N on grain yield of maize at different plant density levels in the southern Guinea savanna of Nigeria

Density (plants/ha)	Response function[a]	R^2	Maximum yield	Optimum nitrogen (kg/ha)	Response (kg grain/ kg N)
Mokwa					
24 000	$Y = 2206.2 + 29.1N - 0.11N^2$	0.255	4130.7	132.3	31.2
48 000	$Y = 2857.5 + 54.5N - 0.22N^2$	0.519	6232.8	123.9	50.3
72 000	$Y = 2016.5 + 57.8N - 0.21N^2$	0.806	5993.7	137.6	43.6
Omu-Aran					
24 000	$Y = 1763.2 + 26.9N - 0.094N^2$	0.470	3687.7	143.1	25.8
48 000	$Y = 2449.3 + 50.7N - 0.199N^2$	0.721	5678.6	127.4	44.6
72 000	$Y = 1948.7 + 47.3N - 0.197N^2$	0.758	4787.9	120.1	39.9

[a]Y = Yield (kg grain/ha) N = Nitrogen (kg N/ha)

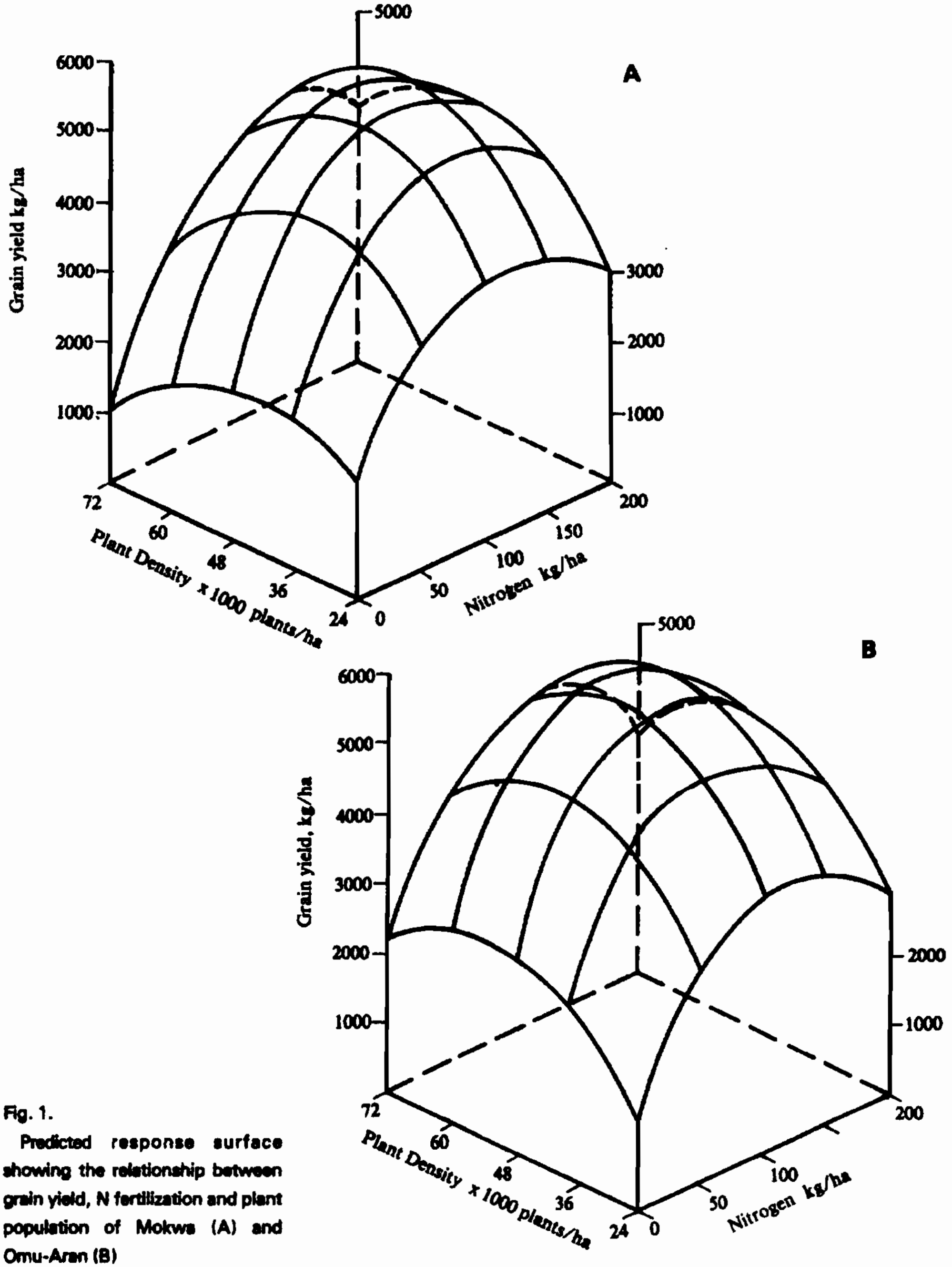

Fig. 1.

Predicted response surface showing the relationship between grain yield, N fertilization and plant population of Mokwa (A) and Omu-Aran (B)

TABLE 7 Effect of applied N and plant density on some yield components of maize at Mokwa

Variable	Year	Intercept	b_1 (N)	b_2(D)	b_3 (N^2)	b_4 (D^2)	b_5 (ND)	R^2
No. of kernels/ear	1976	402.9	1.068**	-0.002	-0.004**	0.3×10^{-8}	0.2×10^{-5}	0.584
	1977	414.6	0.654**	-0.001	-0.003**	-0.4×20^{-8}	0.5×10^{-5}	0.730
Weight/1000 kernels(g)	1976	339.6	0.145	-0.001	0.001	0.3×10^{-8}	0.1×10^{-5}	0.212
	1977	295.5	0.289	-0.002*	-0.002*	0.2×10^{-7}	0.1×10^{-5}	0.296
No. of ears/ plant	1976	1.0	0.004**	-0.5×10^{-5}	-0.2×10^{-4}**	0.2×10^{-10}	0.4×10^{-8}	0.652
	1977	0.87	0.003**	0.1×10^{-5}	-0.1×10^{-4}*	-0.7×10^{-10}	0.1×10^{-7}	0.606
Days to 50% tasselling	1976	62.6	-0.02	0.1×10^{-3}	0.1×10^{-3}	-0.6×10^{-9}	-0.3×10^{-6}	0.307
	1977	59.2	-0.004	0.8×10^{-4}	0.2×10^{-5}	-0.6×10^{-9}	-0.3×10^{-7}	0.101
Days to 50% silking	1976	69.9	-0.05*	0.1×10^{-3}	0.3×10^{-3}**	-0.2×10^{-9}	-0.6×10^{-6}	0.456
	1977	69.2	-0.08**	0.4×10^{-4}	0.2×10^{-3}**	0.4×10^{-10}	-0.8×10^{-7}	0.666
Shelling percentage	1976	82.4	0.065**	-0.9×10^{-4}	-0.3×10^{-3}**	0.2×10^{-9}	0.1×10^{-7}	0.299
	1977	92.0	-0.028	-0.340	-0.5×10^{-5}	0.2×10^{-8}	0.6×10^{-6}	0.263

* ** Significant at the 0.05 and 0.01 confidence levels, respectively

in Table 6. The relatively higher N-use efficiency at both locations when maize was planted at a population density of about 50,000 plants/ha apparently indicated the superiority of this population density over the other two. It is obvious that optimum density of planting is variable, depending on a multitude of factors such as geographical location, soil fertility, cultivar planted, weed control measures and availability of moisture in the soil. In general, however, a plant population density of about 50 000 plants/ha may be regarded as being adequate for maximum maize yield in this ecological zone.

Yield components

Components of yields were recorded only at the Mokwa location. In spite of the lower grain yield reported for 1976 as compared with 1977 (Table 3), the number of kernels per ear and the 1000-kernel weight were significantly higher and numbers of days to tasselling and silking appreciably greater in 1976 than in 1977. Since adverse weather conditions such as poor rainfall distribution, especially during the critical stages of tasselling, silking and grain filling, are known to have adverse effects on the number of kernels per ear and the 1000-kernel weight, which could lead to reduction in total grain yield, the lower grain yield recorded in 1976 as compared with 1977 at Mokwa might be attributed partly to poor weather conditions and largely to poor management. The number of ears per plant and the shelling percentage were not affected by seasons in this study.

Numbers of kernels per ear and ears per plant were favourably influenced by applied N (Table 7). Since the final grain yield of maize is usually determined by its major yield components such as the number of kernels per ear, number of ears per plant and weight per kernel, the increase in grain yield with increase in applied N could probably be due to the positive effects of N application on such yield components. A low rate of applied N tended to favour early silking while high N rate delayed it. Shelling percentage was increased by a low rate of N and decreased by a high N rate.

The plant population densities used in this study appeared to have no substantial effect on numbers of kernels per ear and ears per plant, shelling percentage and days to 50% tasselling (Table 7). The lack of responses of these variables to increase in plant density are not consistent with results reported by Bryan *et al.* (1940), Lang *et al.* (1956) and Thomas (1956) who observed decreases in these yield components, with the exception of numbers of days to tasselling and silking, as plant density increased. Such observed decreases have been attributed to the stress which plants suffer as a result of interplant competition when they are crowded together.

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