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Response of two maize varieties to density and nitrogen fertilizer in the highland zone of Rwanda

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ABSTRACT

Objectives: To determine grain yield response to plant density and N fertilizer application in maize (*Zea mays* L.) and formulate appropriate recommendations for growers in the highland (1800 to 2400 m asl) zone of Rwanda.

Methodology and results: Two open-pollinated maize varieties, Mamesa (early maturing) and Tamira (late maturing) were evaluated at three densities (30 000, 50 000 and 70 000 plants ha^{-1}, coded as D1, D2 and D3, respectively and three N levels (0, 80, 160 kg N ha^{-1}) using a split-split plot design at Ruhengeri and Tamira in the highland zone during the 2007/08 growing season. Varieties were randomized in the main-plots, plant densities in the sub-plots, and N levels in the sub-sub plots with three replications per location. The density x nitrogen interaction was significant and optimum N rates for maximum grain yields from response curves were determined to be 107, 112 and 117 kg N ha^{-1} for D1, D2 and D3, respectively. Predicted yields at the optimum N levels were 5.90 t ha^{-1} for D1, 7.70 t ha^{-1} for D2 and 7.90 t ha^{-1} for D3, and were all not significantly different from yields at the usually recommended rate of 80 kg N ha^{-1}.

Conclusion and application of findings: A population of 50 000 plants ha^{-1} and application of 80 kg N ha^{-1} gave the highest yields and is recommended for profitable maize production in the highland zone of Rwanda.

Key words: Plant density, nitrogen response, highland, maize cultivars

INTRODUCTION

Maize (*Zea mays* L.) is an important staple cereal in small-scale, rain-fed production systems in the highland (1800 to 2400 m asl) zone of Rwanda. The crop covers about 114,800 ha in the country (FAO, 2009) but production is concentrated mainly in the highland zone. As a staple, it is consumed in several traditional food preparations (Nyirigira *et al*., 2005) and is increasingly becoming a major component of livestock feed in the country. However, annual production is often short of demand and grain has to be imported. In 2006, a total of 91,813 tons of grain was produced from approximately 114,836 ha and 29,076 tons had to be imported to supplement domestic production (FAO, 2009). Farm productivity is therefore low, averaging about 0.8 t ha^{-1}. Improving productivity will require adoption of improved cultivars and appropriate crop management practices by growers (Sallah *et al*., 2007).

Two important agronomic practices for increasing productivity are optimum plant population densities and nitrogen fertilizer regimes.

Several studies have reported plant density and nitrogen fertilizer responses in maize (Carlone and Russell, 1987; Sallah *et al*., 1997; Akinnifesi *et al*., 2007). Akinnifesi *et al*. (2007) reported that application of 80 kg N ha^{-1} is required for maximum grain yield in mono-cropped maize in Malawi. Carlone and Russell (1987) observed that the effects of plant densities and N fertilizer rates in maize are not independent and that a cultivar requires a specific density x N level combination for maximum yield. Sallah *et al*. (1997) recommended 50 000 plants ha^{-1} density and application of 90 kg N ha^{-1} for optimal maize production in the Guinea savannah zone of Ghana.

Information on density x N fertilizer response in maize is scanty in Rwanda. Kelly and Murekezi (2000) analysed data from on-farm evaluations and concluded that application of 80 to 100 kg N ha^{-1} would be necessary for profitable maize production in the highland zone of Rwanda. However, confounding effects of various unspecified levels and quality of farmyard manure applied to the experimental fields by farmers rendered the data less reliable (Kelly and Murekezi, 2000). The objective of the present study was to determine grain yield responses of two maize varieties to plant densities and N fertilizer application in the highland zone of Rwanda.

MATERIALS AND METHODS

Two improved maize varieties in the highland zone, namely Mamesa (early maturing, yellow) developed from CIMMYT Pool 8A and Tamira (late maturing, white) synthesised from CIMMYT Pool 9A (Ngaboyisonga *et al*., 2007), were evaluated at three plant densities (D1=30 000, D2=50 000, D3=70 000 plants ha^{-1}) and three N fertilizer levels (N1=0, N2=80, N3=160 kg N ha^{-1}) at two locations during the 2007/08 growing season. The trials were established on a farmer's field at Ruhengeri (Lat. 1^0 27′ S, Long. 29^0 35′ E; 1,860 m asl) and at the Experimental Station of the Institut des Sciences Agronomiques du Rwanda (ISAR) at Tamira (1º 55' S; 29º 38' E; 2,340 m asl). Both locations have soils derived from volcanic parental materials and are considered to be the best agricultural lands in Rwanda.

The experimental fields were ploughed manually at each site using hoe before planting. At each site, the soil was sampled before final land preparation and analysed for chemical properties (Table 1). Phosphorus and potassium were broadcast over all plots at 60 kg P_2O_5 ha^{-1} as triple super phosphate and 30 kg K_2O ha^{-1} as muriate of potash, and then harrowed manually by hoe prior to sowing. The experiment was a complete factorial in a randomized complete block design arranged in split-split plots with three replications per site. Varieties (Mamesa, Tamira) were assigned randomly to the main plots, densities (D1, D2, D3) to the sub-plots, and N levels (N1, N2, N3) in the sub-sub plots. The sub-sub plots consisted of four 5-m long rows of each variety. Rows were spaced at 0.75 m and three seeds were planted within rows at 0.44, 0.25 and 0.19 m to attain the target populations of 30 000, 50 000 and 70 000 plants ha^{-1}, respectively, after thinning to one plant per hill. The source of N was urea and ring-application of the required N was made following thinning at two weeks after planting. The urea was buried by ridging immediately after application to avoid loss due to volatilization.

Hand-weeding was done and ridges re-made using the hoe when necessary to keep the plots free of weeds in each environment. Data were taken from the two middle rows of the sub-sub plot of each variety on days to 50% silking, days to 50% anthesis, anthesis-silking interval (ASI), plant height, pests and diseases, number of ears per plant, and grain yield. Anthesis-silking interval was calculated as the difference between days to 50% silking and 50% pollen shed. *Turcicum* or northern leaf blight, maize streak virus and rust disease symptoms were scored on a 1 to 5 scale. 1 denoting apparently healthy plants, and 5 denoting all plants bore symptoms. Stem borer infestation was scored on a similar 1 to 5 damage scale, grain yield was expressed in kg ha^{-1} at 15% moisture content.

Data were analyzed by site and combined over all sites using the GenStat (2007) Discovery Edition 3.0 statistical software, assuming location effects were random and variety, plant density and N effects fixed. Orthogonal polynomials were used to calculate linear and quadratic effects of densities and N levels and their interactions for yield, as well as regression coefficients of yield on plant densities and N levels (Little and Hills, 1977). The regression coefficients were used to determine the yield response to increasing plant density and N fertilizer application. Optimum N levels as well as yields at these levels were estimated from the resulting quadratic response curves.

RESULTS AND DISCUSSION

Chemical properties of the soils at the two experimental sites are detailed in Table 1. The soils were slightly acidic with moderate organic carbon contents around 2.0% at both sites, moderate available N at Ruhengeri and high N at Tamira. The soil assimilable P was high at Ruhengeri but very low at Tamira, exchangeable cation levels were very high for K at both sites, high for Ca at Ruhengeri and very high at Tamira, and high for Mg at both sites. Table 2 shows the analysis of variance combined over the two environments (locations) for grain yield. Environments (E) significantly (p=0.03) influenced grain yields of the two varieties (Table 2). Conditions during the season were generally favourable for plant growth and development in both environments.

Table 1: Chemical properties of soils at Ruhengeri and Tamira experimental sites in the highland zone of Rwanda.

Soil properties	Ruhengeri	Tamira
pH - H_2O	6.30	6.20
- KCl	5.60	5.40
Organic carbon (%)	2.01	2.08
N (%)	0.25	0.66
P (mg/kg)	110.10	2.68
K (cmol/kg)	2.01	2.08
Ca (cmol/kg)	14.40	26.00
Mg (cmol/kg)	5.80	6.60

As a consequence, yields were typically high, averaging 5.14 t ha^{-1} at Tamira station and 6.94 t ha^{-1} at Ruhengeri. The two varieties (V) differed significantly (p=0.009) in grain yield potential in the highland environment (Table 2). The early maturing cultivar Mamesa yielded 5.72 t ha^{-1} compared to 6.37 t ha^{-1} for the late maturing variety Tamira, representing 11.4 % yield superiority. The V x E interaction was highly (p=0.001) significant for yield (Table 2), indicating differential response of the varieties in the two environments. Variety Tamira was 8.5 % more productive at Ruhengeri representing the warmer parts (1800 to 2000 m asl) of the highland zone whereas variety Mamesa yielded 28.2 % higher at Tamira station representing the colder parts (>2000 m asl) of the highland zone. This observation confirms the superior performance of Mamesa in colder environments in the highland which is well-known to producers. For this reason, Mamesa is the most popular cultivar, covering about 95.0 % of the maize fields in areas above 2000 m asl in Rwanda (Sallah *et al*., 2007).

Differences among plant densities (D) for grain yield were highly (p<0.001) significant (Table 2). Yields increased by 23.6 % from 30 000 to 50 000 plants/ha and by 3.3 % from 50 000 to 70 000 plants ha^{-1} (Fig. 1). The linear and quadratic responses to plant density were, therefore, highly significant (Table 2). The D x E or V x D interaction was not significant but the V x D x E as well as the V x E interactions with the linear response to density were significant (Table 2). The non-significant V x D interaction suggests that both varieties exhibited similar response to increasing plant population.

Differences among N fertilizer levels for grain yield were highly (p<0.001) significant (Table 2). Yields averaged 4.5 t ha^{-1} at 0 kg N/ ha, increased by 54 % when N was applied at 80 kg ha^{-1}, but decreased by 3.5 % when N was increased from 80 to 160 kg ha^{-1} (Fig. 2). Consequently, the linear and quadratic responses to N application were highly (p<0.01) significant (Table 2). The data indicated that application of N beyond 80 kg ha^{-1} may not be beneficial for increasing yield. Limited supplies of other essential mineral nutrients, particularly micro-elements in the soils probably account for the lack of significant response to N beyond 80 kg ha^{-1} and needs to be investigated. These findings are in close agreement with those of Kelly and Murekezi (2000) who recommended applications of 80 to 100 kg N ha^{-1} to maize in the highland zone of Rwanda. The N x E interaction for yield was highly (p<0.001) significant; so were the interactions between the linear and quadratic responses of N with the environment (Table 2). These suggest differential response to N at the two locations, due to differences in elevation and temperature, as well as in soil properties. Tamira (2,340 m asl) is at a higher elevation than Ruhengeri (1,860 m asl) and has soils that are more acidic and generally less fertile (Table 1).

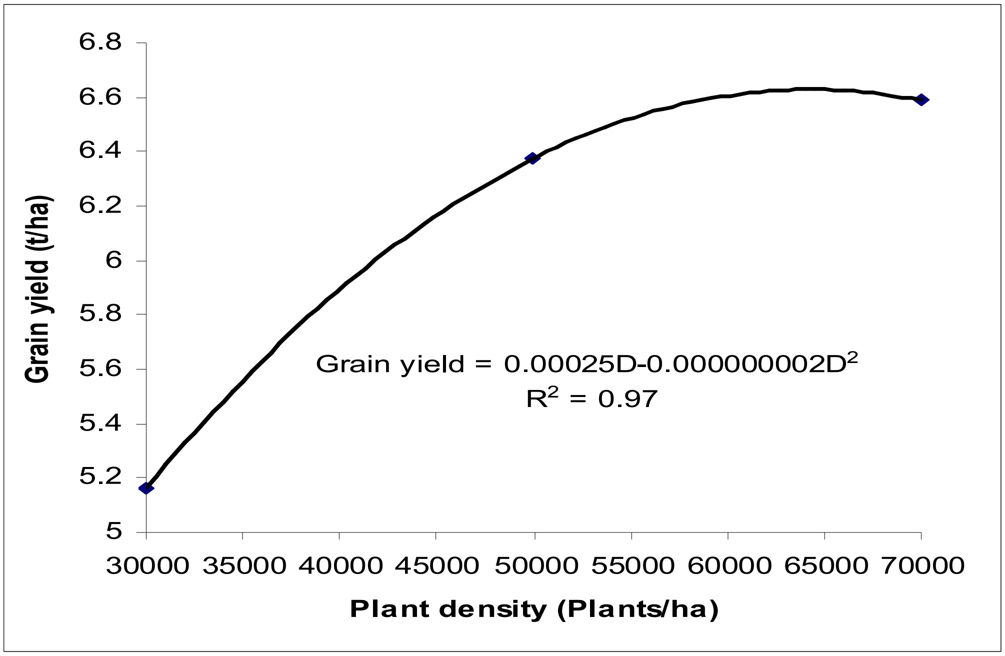

Figure 1: Grain yield response to increasing plant population in Mamesa and Tamira maize varieties in the highland zone of Rwanda.

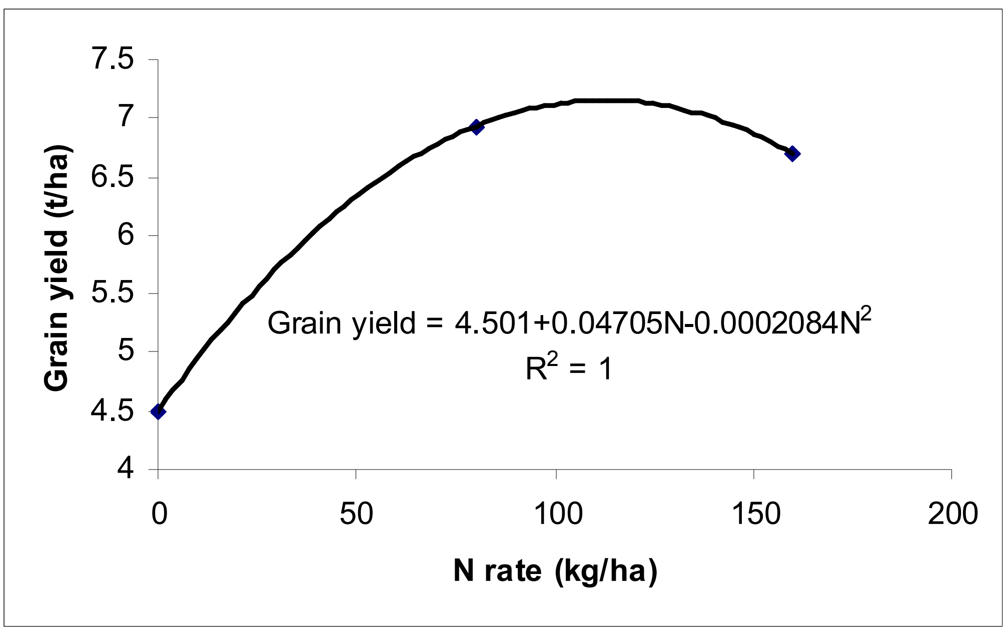

Figure 2: Grain yield response to N fertilizer application in Mamesa and Tamira maize varieties in the highland zone of Rwanda.

Nitrogen fertilizer requirement of a crop depends on many factors, including yield goal, inorganic soil N, potential N mineralization and soil type (Schlegel & Havlin, 1995). Grain yields observed at zero N were high, averaging 4.5 t ha^{-1} in this study. Chemical analyses of the soils at the experimental sites showed moderately high organic carbon contents and moderate to high available N, which are indicative of high initial soil fertility at both sites. The high yield observed at zero N was, therefore, attributed to this initial high soil fertility.

The V x N interaction as well as the interaction between variety and the linear and quadratic components of the response to N were not significant, suggesting both varieties showed similar N response patterns for grain yield (Table 2). The D x N interaction was, however, significant (p=0.023) and their linear x linear interactions were also highly (p=0.004) significant; but the other interaction components were not (Table 2). The V x N x E interaction as well as the interaction of V x E with the quadratic response to N were highly (p<0.01) significant. The D x N x E, V x D x N and V x D x N x E interactions were all not significant (Table 2).

The significant D x N interaction and their linear x linear interactions indicated that neither the density nor N effect should be interpreted independently (Carlone & Russell, 1987). This suggests that as plant population increases, higher N fertilizer application rates are needed for higher yields (Fig. 3). At 30 000 plants ha^{-1} density (D1), yields were lower at all levels of applied N than at either 50 000 plants ha^{-1} (D2) or 70 000 plants ha^{-1} (D3). Similarly, yields were lower for D2 than D3 at all N levels but differences were small and not significant (Fig. 3). Consequently, the following quadratic equations were used to estimate the optimum N application rate and expected grain yields at each plant density (D1, D2 and D3):

$Yield_{D1} = 4191 + 31.7N - 0.147N^2$, $R^2 = 1.0$;

$Yield_{D2} = 4638 + 54.4N - 0.242N^2$, $R^2 = 1.0$;

and

$Yield_{D3} = 4675 + 557N - 0.247N^2$, $R^2 = 1.0$;

Where: $Yield_{(D1,D2, D3)}$ is the grain yield in kg ha^{-1}

D1 = 30 000 plants ha^{-1}, D2 = 50 000 plants ha^{-1} and D3 = 70 000 plants ha^{-1});

N is the nitrogen fertilizer rate in kg N ha^{-1}.

The biological optimum N rates for maximum grain production from these equations were 107, 112 and 117 kg N ha^{-1} for D1, D2 and D3, respectively. The predicted grain yields at the optimum N levels were 5901 kg ha^{-1} for D1, 7695 kg ha^{-1} for D2, and 7897 kg ha^{-1} for D3.

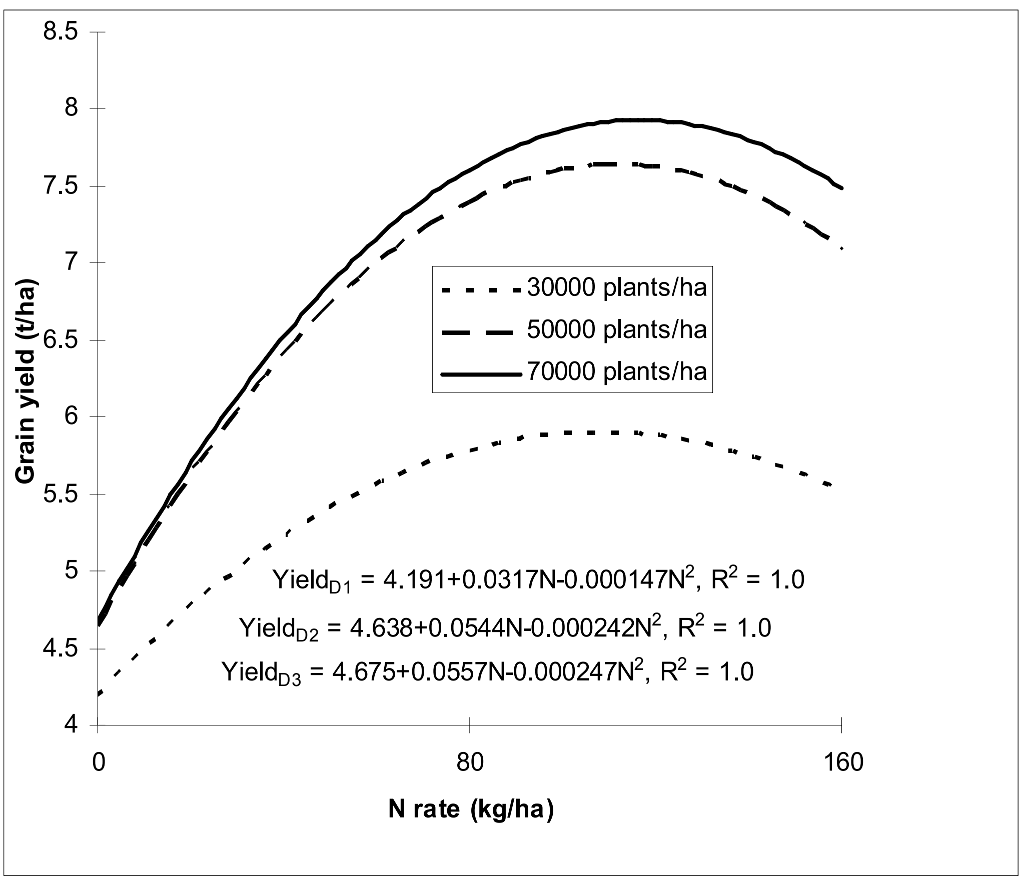

Figure 3: Grain yield response to nitrogen fertilizer application at three plant densities in Mamesa and Tamira maize varieties in the highland zone of Rwanda.

Table 2: Mean squares and significant levels from the analyses of Variance for grain yield of two maize varieties evaluated at three plant densities and three N levels in Rwanda, 2007/08 season.

Source of variation+	df	Mean squares	P-value
Replication	2	2,730,116	0.995
Environment (E)	1	86,953,810	0.030
Error(a)	2	2,754,105	
Variety (V)	1	11, 393,750	0.009
V x E	1	30,886,944	0.001
Error(b)	4	493,215	
Density (D)	2	21,264,050	< 0.001
$D_{linear(l)}$	1	36,548,411	< 0.001
$D_{quadratic(q)}$	1	5,979,688	0.006
D x E	2	809,716	0.290
D_l x E	1	229,532	0.546
D_q x E	1	1,389,899	0.149
V x D	2	886,135	0.260
V x D_l	1	1,613,963	0.122
V x D_q	1	158,307	0.616
V x D x E	2	2,613,530*	0.032
V x D_l x E	1	2,836,196	0.046
V x D_q x E	1	2,390863	0.064
Error (c)	16	604,456	
Nitrogen (N)	2	64,572,388	< 0.001
N_l	1	86,443,133	< 0.001
N_q	1	42,701,644	< 0.001
N x E	2	12,313,122	< 0.001
N_l x E	1	17,301,961	< 0.001
N_q x E	1	7,324,284	0.003
V x N	4	2,289,442	0.052
V x N_l	1	2,486,946	0.071
V x N_q	1	2,091,939	0.097
V x D	4	2,282,934	0.023
D_l x N_l	1	6,648,128	0.004
D_q x N_l	1	600,878	0.368
D_l x N_q	1	1,391,672	0.173
D_q x N_q	1	491,056	0.416
V x N x E	2	6,563,624	0.001
V x N_l x E	1	2,954,540	0.050
V x N_q x E	1	10, 172,708	0.001
D x N x E	4	391,180	0.709
V x D x N	4	697,364	0.439
V x D x N x E	4	1,277,178	0.154
Error(d)	48	728,042	
Total	107		

+ D_l and N_l denote the linear(l) response and D_q and N_q the quadratic(q) response to density (D) and nitrogen (N), respectively.

The response of the other agronomic traits of the two varieties to plant density and N fertilizer application is presented in Tables 3 and 4. Location effects were highly significant ($p<0.01$) for male and female flowering and plant height, but significant ($p<0.05$) for anthesis-silking interval (ASI), ears per plant, and grain moisture at harvest (Table 3). Effects among varieties were highly significant for male and female flowering and grain moisture, but significant for plant height, lodging; *Turcicum* leaf blight and rust disease ratings, ears per plant, and ear length (Table 3). The location x variety interaction was highly significant for male and female flowering and significant for plant height (Table 3). Density effects were highly significant for plant height, ears per plant and ear length; and nitrogen effects for male and female flowering, ASI, ears per plant and grain moisture (Table 3). The location x nitrogen interaction was highly significant only for female flowering and ASI. All other main effects and interactions were not significant for any of the remaining traits (Table 3).

Table 3: P-values for significant effects from the analyses of variance for other agronomic traits in two maize varieties (V) evaluated at three plant densities (D) and three N levels in the highland zone of Rwanda in 2007/08 season.

Traits	Location (L)	Variety (V)	LxV	Density (D)	Nitrogen (N)	LxN
Mid-anthesis (days)	0.001	0.002	0.001		<0.001	
Mid-silk (days)	<0.001	0.005	<0.001		0.001	0.005
Anthesis-silking interval (ASI) (days)	0.030				0.001	0.009
Plant height (cm)	<0.001	0.045	0.040	0.009		
Lodging (%)		0.041				
Turcicum leaf blight (score+)		0.02				
Rust (score)		0.02				
Ears per plant (number)	0.044	0.035		<0.001	0.004	
Ear length (cm)		0.026		0.001		
Grain moisture (%)	0.035	0.006			0.040	

+ Scoring on 1 to 5 scale, 1 denoting clean plants, no apparent disease symptoms and 5 denoting all plants bore symptoms.

Since the variety x density or the variety x nitrogen interaction was not significant for any of these agronomic traits (Table 3), the nature of the response to increasing plant density and N application in the two varieties for these traits can be deduced wholly from the main factor effects. Compared to Tamira, variety Mamesa flowered two weeks earlier, had taller plants, was more susceptible to lodging, and possessed shorter ears with lower grain moisture content at harvest (Table 4). Small but significant differences were detected between the two varieties for reaction to *Turcicum* leaf blight and rust diseases, as well as number of ears per plant; with each plant carrying one ear (Table 4). In general, N application reduced the number of days to male and female flowering and ASI, and increased the number of ears per plant (Table 4). Small but significant N effects were also observed for plant height, lodging, *Turcicum* and rust diseases, and grain moisture at harvest (Table 4). Hence, N fertilizer application promoted early flowering and good male-female flowering synchrony, and increased the number of ears per plant, in addition to grain yield.

Optimum N levels for maximum yields ranged from 50 to 170 kg N ha^{-1} in the humid and sub-humid tropics (e.g. Sallah *et al*., 1997; Sipaseuth *et al*., 2007) and from 110 to 220 kg N ha^{-1} in the temperate zone (e.g. Carlone and Russell, 1987; Kahabka *et al*., 2004). Although optimum biological N rates are important, they may not necessarily be the economical rates for recommending to growers. In this study, the greatest yield response was observed at 80 kg N ha^{-1} for all plant densities and N application beyond this rate did not lead to increased yield (Fig. 3). There was also no significant difference between yields for D2 and D3 at all N levels. These results implied that there was no advantage in increasing plant population beyond 50 000 plants ha^{-1} or applying more than 80 kg N ha^{-1} to maize.

Recommendations from this study apply mainly to mono-cropped maize and not to maize in intercrops, e.g. with potatoes, beans etc as found in the volcanic highlands of Rwanda (Sallah *et al*., 2007). Appropriate plant population and fertilization regimes need to be developed for these cropping systems as well.

Based on the findings of this study, a population of 50 000 plants ha^{-1} and an application of 80 kg N ha^{-1} is hereby recommended for profitable maize production in the highland zone of Rwanda.

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Table 4: Means of 11 agronomic traits in two maize varieties evaluated at three plant densities and three N rates in the highland zone of Rwanda in the 2007/08 season.

Nitrogen applied (kg N ha^{-1})	Variety	Mid-anthesis (days)	Mid-Silk (days)	ASI (days)	Plant height (cm)	Lodging (%)	*Turcicum* leaf blight (score)+	Rust (score)	Maize streak virus (score)	Ears per Plant (no.)	Ear Length (cm)	Grain Moisture (%)
0	Mamesa	107	113	5.7	233	9.7	2.7	1.1	1.4	0.9	18	22.0
	Tamira	121	128	6.4	219	6.9	2.3	2.3	1.5	1.1	20	27.1
	Mean	114	120	6.1	226	8.3	2.4	1.9	1.4	1.0	19	24.6
80	Mamesa	105	110	4.9	233	9.1	2.8	1.3	1.3	1.0	18	21.6
	Tamira	120	125	5.2	224	4.8	2.2	2.7	1.4	1.1	20	25.1
	Mean	113	118	5.1	229	7.0	2.5	2.0	1.4	1.1	19	23.3
160	Mamesa	105	110	5.1	234	10.0	2.7	1.2	1.3	1.1	19	21.3
	Tamira	120	124	5.3	218	7.0	2.0	2.7	1.5	1.2	20	27.1
	Mean	112	118	5.2	226	8.5	2.4	1.9	1.4	1.1	19	24.2
Overall	Mamesa	106	111	5.3	233	9.6	2.7	1.2	1.4	1.0	18	21.6
	Tamira	120	126	5.7	220	6.3	2.1	2.7	1.5	1.1	20	26.4
	Mean	113	119	5.5	226	7.9	2.4	1.9	1.4	1.1	19	24.0
LSD (0.05) for comparing main effect means:												
Nitrogen		0.7	0.7	0.6	6.8	1.8	0.2	0.2	NS	0.08	NS	0.9
Variety		1.3	1.6	NS	9.3	1.7	0.2	0.4	NS	0.07	0.6	1.4

+ Scoring on 1 to 5 scale, 1 denoting clean plants, no apparent disease symptoms and 5 denoting all plants bore symptoms.

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