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Effect of Plant Density and Nitrogen Fertilizer Rate on Growth, Nitrogen Use Efficiency and Grain Yield of Different Maize Hybrids under Rainfed Conditions in Southern Vietnam

Dinh Hong Giang[1,2], Ed Sarobol[2,*] and Sutkhet Nakasathien[2]

ABSTRACT

Plant density (PD) and nitrogen (N) fertilizer are considered the most important crop management practices in improving maize grain yield. Two identical field experiments in Vietnam, in Ba Ria and Dong Nai provinces, were conducted in the wet season 2011 to study the effects of PD and the N fertilizer rate on two maize hybrids. The experiment was laid out in a split-split plot in a randomized complete block design with three replications. Two maize hybrids, NK7328 and LVN10, constituted the main plots and three PD values (57,000, 71,000, and 84,000 plants.ha^{-1}) were the subplots. Five N rates (0, 60, 120, 180 and 240 kg.ha^{-1}) were the sub subplots. The results revealed that NK7328 had a greater leaf area index (LAI) than LVN10 (4.32 versus 3.92 and 4.31 versus 4.11) at both Ba Ria and Dong Nai, respectively. NK7328 also had a greater grain yield than LVN10 at both locations (8.11 versus 7.15 and 8.04 versus 6.72 t.ha^{-1}, respectively). This greater grain yield in these experiments was attributed to a greater number of kernels per ear (KNo) and a greater 1,000-kernel weight (KWt). NK7328 exhibited higher nitrogen use efficiency (NUE) than LVN10 (27.0 versus 21.4 and 29.3 versus 16.4, respectively). Increased PD from 57,000 to 84,000 plants.ha^{-1} and increased N application rate from 0 to 180 kg.ha^{-1} increased the anthesis-silking interval and LAI. The grain yield, KNo and KWt decreased with the increased PD and decreased N fertilizer rate. The NUE of the maize hybrid was significantly affected by the N fertilizer rate but there was no effect from PD. The NUE was not associated with the maize grain yield. The optimum PD and N rate were 71,000 plants.ha^{-1} and 120 kg.ha^{-1} to be applied for maize under rainfed conditions in southern Vietnam.

Keywords: nitrogen, nitrogen use efficiency, leaf area index, maize hybrid, plant density

INTRODUCTION

Maize (*Zea mays* L.) is one of the major food crops grown in Vietnam and is cultivated in diverse environments being a primary source of feed for Vietnam's poultry and livestock industry (Ha *et al*., 2004). In southern Vietnam, maize has been planted on approximately 0.3 million ha with a total grain production of more than 1.2 million t mainly under rainfed conditions (General Statistics Office, 2011). However, the average national yield is only 4 t.ha^{-1} which is far below the potential yield of commercial maize hybrids and according to Witt *et al*. (2006) maize growers need to adjust the timing and amount of fertilizer (N, P, and K) to increase yield and profitability.

1 Research and Development Department, Syngenta Vietnam Company, Dong Nai, Vietnam.

2 Department of Agronomy, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand.

* Corresponding author, email: agred@ku.ac.th

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Plant density (PD) is considered one of the most important crop management practices and has an impact on grain yield (Gardner *et al.*, 1985). Increased PD and decreased row spacing have contributed to the increase in grain yield per unit area (Westgate *et al*., 1997). Increasing the yielding ability of newer maize hybrids is owed primarily to the increase in stress tolerance that in turn provides tolerance to higher plant densities (Duvick, 2005). Moreover, the information on a suitable plant population for each maize cultivar is one of the key factors for planning maize production (Bavec and Bavec, 2002). Under favorable conditions in tropical Asia, plant densities of 65,000 to 75,000 plants.ha^{-1} are required to achieve high yields (Witt *et al*., 2006). The results from Hao and Hai (2008) indicated that a higher grain yield was obtained at a PD of 70,000 to 80,000 plants. ha^{-1}. Among plant nutrients, nitrogen (N) is the most important and essential for growing crops (Gardner *et al*., 1985). Therefore, there have been many studies determining the effect of N fertilizer on the growth and production of maize (Alam *et al*., 2003; Kien *et al.*, 2008; Pokharel *et al*., 2008). In fact, there are few studies to date that have evaluated the simultaneous effects of density and N fertilizer rate for hybrids and locations in Vietnam. In addition, the efficient use of nitrogen is an important goal in maximizing yield in ways that have a minimal impact on the environment. On the other hand, the nitrogen use efficiency (NUE) among maize hybrids differed significantly with the amount of nitrogen supply and the variation in utilization of accumulation and uptake efficiency (Moll *et al*., 1982). Therefore, the objectives of the current study were to: 1) assess the effect of plant densities and N fertilizer rates on the grain yield and nitrogen use efficiency of two maize hybrids; and 2) to determine an optimum plant density and N fertilizer rate for maize hybrids under rainfed conditions in southern Vietnam.

MATERIALS AND METHODS

The experiments were carried out in Ba Ria (10°35'N, 107°17'E) and Dong Nai (11°03'N, 107°16'E) provinces in southern Vietnam during the wet season of 2011 from April to August. Two maize hybrids (LVN10 and NK7328) were examined. The experiment was laid out in a split-split plot in a randomized complete block design with three replications. Two hybrids were allocated in the main plots. Three plant densities (57,000, 71,000 and 84,000 plants.ha^{-1}), with plant spacing of 25, 20 and 17 cm, respectively, were assigned in subplots. Five nitrogen fertilizer rates (0, 60, 120, 180 and 240 kg.ha^{-1}) were applied in the sub subplots. Each plot contained six rows of maize with a plot size of 4.2 m wide and 5 m long and a row spacing of 70 cm. In all treatments, plots were hand planted at three seeds per hill and thinned to the desired plant population at the three-leaf (V3) stage. P was applied at 90 kg.ha^{-1} as single super phosphate and potassium was applied at 90 kg.ha^{-1} as muriatic potash in all sub subplots as a basal application. The five N treatments were applied manually in the form of urea (46% N) at 15 and 30 days after planting (DAP) according to treatments. Atrazine (a pre-emergence herbicide) was applied as recommended for southern Vietnam (Hung, 1999). The crop was protected against insects through a one-time application of insecticides. Before planting at each location, five soil samples over the entire field were taken from 0 to 30 cm depth, air dried, bulked and subsampled for chemical analysis. The results of the chemical analysis are shown in Table 1. The soil types were black soil (humic gleysols) and reddish brown soil (rhodic ferrasols) at Ba Ria and Dong Nai with approximately 3.51% and 1.79% organic matter content, respectively. There was a good rainfall distribution in the 2011 rainy season from April to August at both locations (Figure 1). The temperatures recorded for Ba Ria and Dong Nai during the course of the experiments were similar to their respective averages over the preceding 5

yr period. Thus, the maize plants received good growth conditions throughout the season (Figure 2).

The stage of plant development was assessed for maize hybrids in the field using the method of Ritchie e*t al.* (1996). The number of days to tasseling and silking were recorded when 50% of the tassel was shedding and 50% of the silk was visible, respectively. The length (L) and maximum leaf width (W) were registered at the flowering stage and used to calculate the leaf area (A) according to Equations 1 and 2 (Montgomery, 1911):

$$\text{Leaf area (A)} = \alpha \times L \times W \quad (1)$$

where $\alpha = 0.75$

$$\text{Leaf area index} = A_L / A_G \quad (2)$$

where A_L is the leaf area per plant and A_G is the land area per plant, both in square centimeters.

The grain yield in tonnes per hectare was measured at physiological maturity from the two central rows. The grain yield was adjusted to 15% moisture content.

Data on the number of kernels per ear were calculated from the kernel weight per ear and the corresponding 1,000-kernel weight from Equation 3:

$$\text{Number of kernels per ear} = \frac{\text{Kernel weight per ear (g)}}{\text{Weight of 1,000 kernels (g)}} \times 100 \quad (3)$$

The number of kernels from the sampled ears at harvest was counted and they were weighed to determine the 1,000-kernel weight. The 1,000-kernel weight was adjusted to 15% moisture content and expressed in grams.

Nitrogen use efficiency (NUE) was calculated

Table 1 Soil analysis values in the topmost 0.3 m at the experimental sites.

Experimental site	Chemical analysis					
	pH (H_2O)	Organic matter (%)	N content (%)	P ($mg.kg^{-1}$) Bray 2	K ($mg.kg^{-1}$)	Ca ($mg.kg^{-1}$)
Ba Ria	5.3	3.51	0.17	20	94	0.64
Dong Nai	6.3	1.79	0.12	75	102	0.95

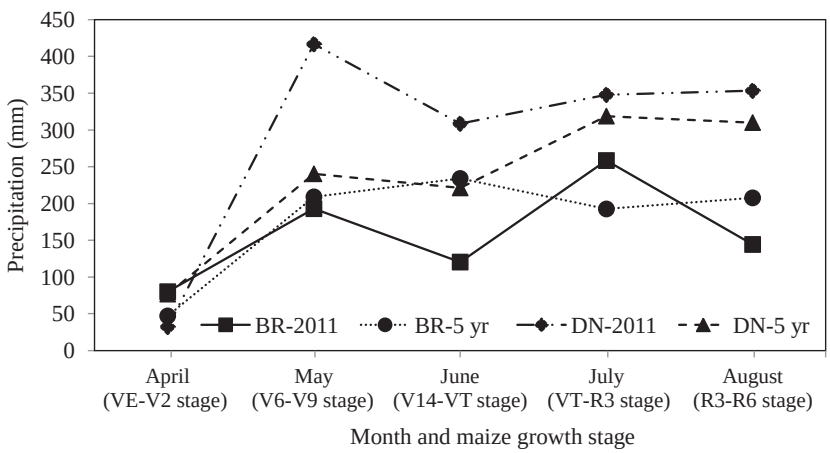

Figure 1 Monthly precipitation data during maize crop growing in 2011 and the mean of the past 5 years (2006–2010): BR-2011= Ba Ria 2011; DN-2011 = Dong Nai 2011; BR-5 yr = Ba Ria mean of 5 yr; DN-5 yr = Dong Nai mean of 5 year; VE = Emergence coleoptiles; V2 = Vegetative stages (two leaves with collar visible) V6 = Vegetative stages (six leaves with collar visible); V9 = Vegetative stages (nine leaves with collar visible); V14 = Vegetative stages (14 leaves with collar visible); VT = Tessel stage; R3 = Kernel milk stage; R6 = Physiological maturity.

using Equation 4 (Cassman *et al*., 2003):

$$NUE = \frac{GY_{fert} - GY_{unfert}}{N \text{ applied}} \quad (4)$$

where GY_{fer} is the grain yield per unit area at 15% moisture content of the treatments receiving N applied and GY_{unfert} is the grain yield per unit area of the treatments without N applied, all measured in kilograms per hectare.

The data were subjected to analysis of variance according to the split-split-plot randomized complete block design using the IRRISTAT software (version 5.0; International Rice Research Institute; Mikari, the Philippines). Separate analysis of variance was done for each parameter. Treatment mean differences were tested using Fisher's least significant difference test at $P < 0.05$.

RESULTS AND DISCUSSION

Plant growth parameters

The results in Table 2 show that PD and the N fertilizer rate had a significant effect on the anthesis-silking interval (ASI) of the two hybrids. Increasing PD increased the ASI in all observations. In contrast, an increased N fertilizer rate decreased the ASI. There was a significant interaction effect of PD and the N rate on the ASI. Longest ASI values were recorded at the lowest N fertilizer rate and the highest PD (Table 3).

The increase in the N fertilizer rate and PD had a significant influence on the plant height and ear height. However, no significant increases in the plant height and ear height were observed when the N fertilizer rate increased from 180 to 240 kg.ha^{-1} (Table 2). The highest plant height and ear height were recorded at a PD of 71,000 plants. ha^{-1} and 180 kg.ha^{-1} (Table 3).

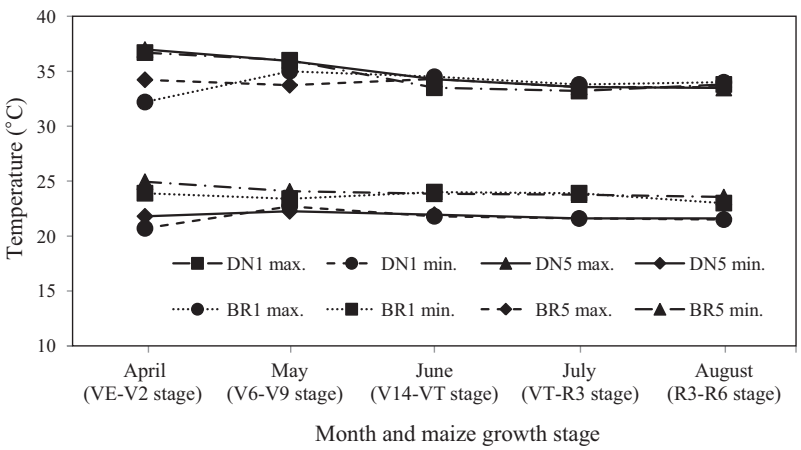

Figure 2 Monthly temperature data during maize crop growing 2011 and the mean of the past 5 years (2006–2010): DN1 max. = Dong Nai maximum temperature; DN1 min. = Dong Nai minimum temperature; DN5 max. = Dong Nai maximum temperature, mean of 5 years; DN5 min. = Dong Nai minimum temperature mean of 5 years; BR1 max. = Ba Ria maximum temperature; BR1 min. = Ba Ria minimum temperature; BR5 max. = Ba Ria maximum temperature, mean of 5 years; BR5 max. = Ba Ria minimum temperature, mean of 5 yr; VE = Emergence coleoptiles; V2 = Vegetative stages (two leaves with collar visible) V6 = Vegetative stages (six leaves with collar visible); V9 = Vegetative stages (nine leaves with collar visible); V14 = Vegetative stages (14 leaves with collar visible); VT = Tessel stage; R3 = Kernel milk stage; R6 = Physiological maturity.

Table 2 Effects of plant density (PD) and N fertilizer rate on anthesis-silking interval (ASI), plant height, ear height and leaf area index (LAI) at tasseling stage of two maize hybrids.

Treatment effect	ASI		Plant height (cm)		Ear height	(cm)	LAI	
(a) Hybrid	BR	DN	BR	DN	BR	DN	BR	DN
NK7328	1.40^{b}	1.20^{b}	226.50	229.60^{b}	126.80^{a}	136.10	4.32^{a}	4.31^{a}
LVN10	2.00^{a}	1.50^{a}	225.10	231.80^{a}	125.50^{b}	137.10	3.92^{b}	4.11^{b}
$LSD_{0.05}$	0.23**	0.20**	n.s.	1.70*	1.20*	n.s.	0.09**	0.10*
(b) PD (plants.ha^{-1})								
57,000	0.90^{c}	0.90^{c}	221.60^{b}	227.80^{b}	121.10^{b}	134.60^{b}	3.52^{c}	3.64^{c}
71,000	1.80^{b}	1.20^{b}	227.70^{a}	231.10^{a}	128.70^{a}	135.60^{b}	4.17^{b}	4.29^{b}
84,000	2.40^{a}	2.00^{a}	229.00^{a}	233.10^{a}	128.80^{a}	137.70^{a}	4.67^{a}	4.70^{a}
$LSD_{0.05}$	0.29**	0.25**	1.90**	2.10**	1.40**	1.70**	0.11**	0.12**
(c) N rate (kg.ha^{-1})								
0	2.30^{a}	1.90^{a}	215.60^{d}	215.40^{e}	116.10^{d}	126.50^{d}	3.23^{d}	3.39^{d}
60	1.90^{b}	1.40^{b}	218.40^{c}	230.10^{d}	120.70^{c}	135.80^{c}	3.79^{c}	3.94^{c}
120	1.50^{bc}	1.20^{b}	227.70^{b}	232.90^{c}	127.60^{b}	138.60^{b}	4.32^{b}	4.42^{b}
180	1.40^{c}	1.20^{b}	232.80^{a}	236.30^{a}	132.70^{a}	141.00^{a}	4.62^{a}	4.60^{a}
240	1.40^{c}	1.10^{b}	234.40^{a}	238.90^{a}	133.80^{a}	141.20^{a}	4.65^{a}	4.70^{a}
$LSD_{0.05}$	0.37**	0.32**	2.40**	2.70**	1.80**	2.20**	0.14**	0.15**
CV(a) %	33.50	42.90	0.90	3.10	3.00	3.80	20.50	20.70
CV(b) %	30.30	48.50	1.40	2.80	2.60	4.10	10.30	9.40
CV(c) %	32.10	35.30	1.60	1.70	2.20	2.40	15.60	17.20

BR = Ba Ria; DN = Dong Nai.
$LSD_{0.05}$ = Least significant difference at 0.05 level.
n.s. = Not significant. * = Significant at 0.05 probability level; ** = Significant at 0.01 probability level.
a–d = Mean values with different lowercase superscripts in a column are significantly different at $P < 0.05$.
CV = Coefficient of variation.

Table 3 Interaction effects of plant density (PD) and N fertilizer rate on anthesis-silking interval (ASI) plant height, ear height and leaf area index (LAI) at tasseling stage of two maize hybrids at Ba Ria.

PD(plants.ha^{-1})	N rate(kg.ha^{-1})	ASI	Plant height (cm)	Ear height (cm)	LAI
57,000	0	1.17^{de}	214.70^{ef}	113.30^{h}	2.76
	60	1.07^{e}	217.70^{ef}	117.00^{g}	3.20
	120	0.67^{e}	221.70^{de}	122.20^{f}	3.67
	180	0.80^{e}	226.70$_{cd}$	126.30^{de}	3.99
	240	0.83^{e}	227.50^{c}	126.70^{d}	4.02
71,000	0	2.17^{cd}	212.80^{f}	116.50^{g}	3.34
	60	2.33^{bc}	216.20^{ef}	122.50^{f}	3.82
	120	1.67^{d}	231.20^{bc}	131.30^{c}	4.31
	180	1.50^{d}	237.00^{a}	137.20^{ab}	4.69
	240	1.50^{d}	236.50^{a}	136.00^{ab}	4.67
84,000	0	3.67^{a}	219.30^{e}	118.50^{g}	3.58
	60	2.83^{b}	221.50^{de}	122.70^{f}	4.34
	120	2.00^{cd}	230.30^{bc}	129.20^{cd}	4.99
	180	1.67^{d}	234.80^{ab}	134.70^{b}	5.18
	240	1.83^{d}	239.20^{a}	138.80^{a}	5.27
$LSD_{0.05}$		0.64*	5.20**	3.20**	n.s.
CV%		32.10	1.60	2.20	15.60

$LSD_{0.05}$ = Least significant difference at 0.05 level.
n.s. = Not significant. * = Significant at 0.05 probability level; ** = Significant at 0.01 probability level.
a–h = Mean values with different lowercase superscripts in a column are significantly different at $P < 0.05$.
CV = Coefficient of variation.

The LAI at the tasseling stage was significantly different between hybrids, among plant densities and N fertilizer rates at both locations (Table 2). NK7328 exhibited a greater LAI than LVN10 at both Ba Ria and Dong Nai (4.32 versus 3.92 and 4.31 versus 4.11, respectively). The LAI increased as the PD increased from 57,000 to 84,000 plants.ha^{-1}. The maximum PD resulted in the greatest LAI of 4.67. There was a significant interaction effect of hybrid and PD at both locations (Figures 3a, 3b). The NK7328 hybrid gave a significantly higher LAI than LVN10 for all three plant densities at Ba Ria, but it was higher for the 57,000 plants.ha^{-1} at Dong Nai. Even though the leaf area of individual plants often declined with each increment of plant density regardless of the N fertilizer rate (Boomsma *et al.*, 2009), these results indicated that increased PD compensated for any accompanying declines in the individual plant leaf area. There was also a significant interaction effect of hybrid and N fertilizer rate (Figures 4a and 4b) at both locations. The LAI increased with increasing N fertilizer rate for both hybrids. The highest LAI was recorded at an N fertilizer rate of 180 kg.ha^{-1}. There was no further improvement in the LAI when the N fertilizer rate was increased from 180 to 240 kg.ha^{-1}. The three-way interaction effects of maize hybrid × plant density × N fertilizer rate were not significant for maize growth parameters at both locations (Table 6).

Grain yield response to plant density

The hybrid NK7328 yielded a significantly greater grain yield than LVN10 by about 13% and 20% at Ba Ria and Dong Nai, respectively. The grain yield of maize increased with increasing PD from 54,000 to 71,000 to 84,000 plants.ha^{-1} (Table 4).

There was a significant interaction effect of hybrid and plant density on grain yield (Figures 5a and 5b). The NK7328 hybrid gave the greater grain yield at PD values of 71,000 and 84,000 plants.ha^{-1} at both locations. The LVN10 hybrid produced a higher grain yield at PD values of 71,000 and 84,000 plants.ha^{-1} at Ba

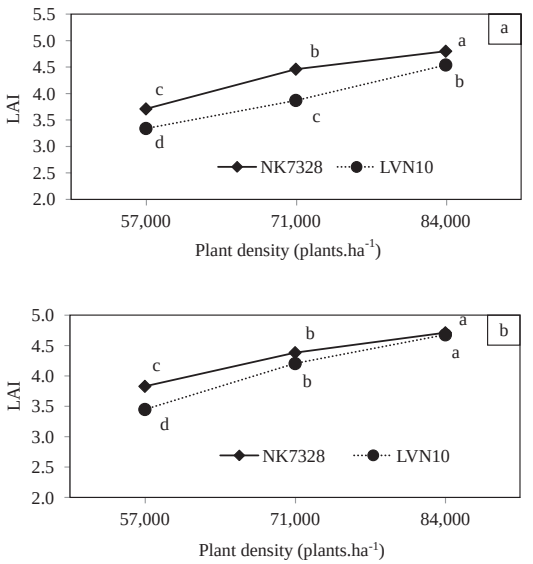

Figure 3 Interaction effects of hybrid and plant density on leaf area index (LAI) at: (a) Ba Ria; (b) Dong Nai. Means with different letters are significantly different $P < 0.05$.

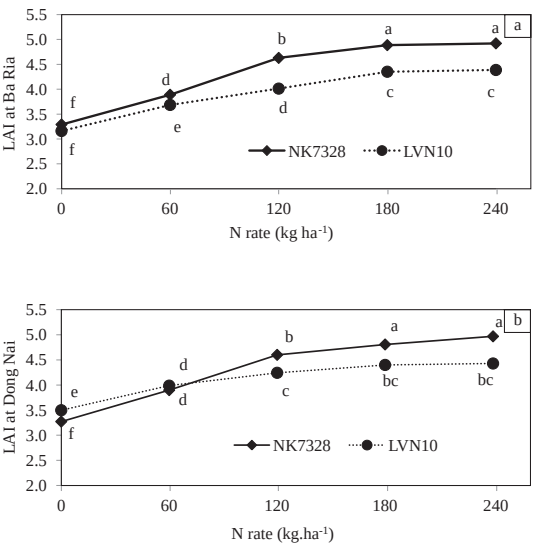

Figure 4 Interaction effects of hybrid and N fertilizer rate on leaf area index (LAI) at: (a) Ba Ria; (b) Dong Nai. Means with different letters are significantly different at $P < 0.05$.

Ria and Dong Nai, respectively. In general, the environmental factors such as climate, moisture and soil fertility also influenced the optimum plant density. A limitation of these environmental factors lowers the optimum plant density for maximum production (Gardner *et al*., 1985). Increased plant density usually caused plants and stems to become smaller, weaker and often taller (Gardner *et al.,* 1985). Some of the greatest concerns about increasing PD are the increased risk associated with lodging and barren plants and this still might be the case but newer hybrids seem to have a much better tolerance to lodging than older hybrids at higher plant densities (Tollenaar, 1989). Some amount of root lodging was observed during the grain filling stage at Ba Ria and the grain yield seemed to be affected by the root lodging in the high plant density treatment (data not shown). This result indicated that the optimum PD to produce a higher grain yield was 71,000 plants.ha^{-1}.

Grain yield response to N fertilizer rate

The N fertilizer rate had a significant effect on the grain yield per unit area of maize hybrid (Table 4). The grain yield per unit area increased with an increasing N fertilizer rate up to 180 kg.ha^{-1} of N. The highest N rate produced the greatest grain yield (8.92 t.ha^{-1}) by an average 74% more than did the lowest N rate.

Table 4 Effects of plant density and N fertilizer rate on grain yield, yield components and nitrogen use efficiency (NUE) of two maize hybrids.

Treatment effect	Grain yield (t.ha^{-1})		Number of kernels per ear		1,000-kernel weight (g)		NUE (kg.kg^{-1})	
	BR	DN	BR	DN	BR	DN	BR	DN
(a) Hybrid								
NK7328	8.11^{a}	8.04^{a}	442.90^{a}	431.50^{a}	315.70^{a}	296.00^{a}	27.00^{a}	29.30^{a}
LVN10	7.15^{b}	6.72^{b}	404.90^{b}	404.80^{b}	306.60^{b}	267.10^{b}	21.40^{b}	16.40^{b}
$LSD_{0.05}$	0.23**	0.25**	6.60**	7.80**	1.90**	2.00**	3.80**	3.60**
(b) PD (plants.ha^{-1})								
57,000	7.17^{c}	6.64^{c}	451.10^{a}	427.80^{a}	330.10^{a}	283.70^{a}	21.40	22.10
71,000	8.06^{a}	7.50^{b}	422.90^{b}	426.20^{a}	301.80^{b}	276.10^{b}	24.10	23.90
84,000	7.67^{b}	8.00^{a}	397.70^{c}	400.30^{b}	301.60^{b}	270.00^{c}	27.20	22.50
$LSD_{0.05}$	0.29**	0.31**	8.10**	9.50**	2.30**	2.50**	n.s.	n.s.
(c) N rate (kg.ha^{-1})								
0	5.16^{d}	5.03^{d}	352.20^{d}	322.90^{e}	263.50^{e}	243.50^{e}	-	-
60	7.03^{c}	7.04^{c}	384.50^{c}	380.50^{d}	294.70^{d}	261.00^{d}	33.00^{a}	33.60^{a}
120	8.33^{b}	8.00^{b}	453.70^{b}	435.30^{c}	319.50^{c}	280.70^{c}	27.30^{b}	24.80^{b}
180	8.72^{a}	8.26^{ab}	457.20^{b}	471.50^{b}	337.20^{b}	296.10^{b}	20.40^{c}	18.00^{c}
240	8.92^{a}	8.60^{a}	471.70^{a}	480.40^{a}	340.90^{a}	301.70^{a}	16.10^{c}	14.90^{c}
$LSD_{0.05}$	0.37**	0.39**	10.50**	12.30**	3.00**	3.20**	5.40**	5.20**
CV(a) %	5.00	11.60	10.30	3.10	3.00	1.80	63.30	86.50
CV(b) %	6.20	11.60	6.80	6.50	2.30	2.40	56.70	51.80
CV(c) %	7.20	7.90	3.70	4.40	1.40	1.70	32.90	33.40

BR = Ba Ria; DN = Dong Nai.

$LSD_{0.05}$ = Least significant difference at 0.05 level.

n.s. = Not significant. * = Significant at 0.05 probability level; ** = Significant at 0.01 probability level.

a–e = Mean values with different lowercase superscripts in a column are significantly different at $P < 0.05$.

CV = Coefficient of variation.

At both locations, least-squares linear regression analysis showed that the grain yield of the two hybrids increased linearly with the increasing N fertilizer rate. At Ba Ria, there was a significant relationship between the grain yield and N rate for the maize hybrid NK7328 (Correlation coefficient $R^2 = 0.85$, $P < 0.05$) and LVN10 ($R^2 = 0.88$, $P < 0.05$) as shown in Figures 6a and 6b. At Dong Nai, the only significant relationship was observed between the grain yield and N fertilizer rate for the maize hybrid NK7328 ($R^2 = 0.89$, $P < 0.05$) as shown in Figure 6c. As an old hybrid, LVN10 has less ability to respond to increased N availability and N uptake to develop kernels, resulting in a lower grain yield. Other research (Rajcan and Tollenaar, 1999) indicated that the total N uptake in the above-ground portions of maize was 10 and 18% greater in the new hybrid than in the old hybrid under low and high soil N conditions, respectively. There was a significant interaction effect between PD and the N fertilizer rate at Ba Ria (Figure 7). The grain yield was not different when the N fertilizer rate was increased from 120 to 240 kg.ha^{-1} at the three plant densities.

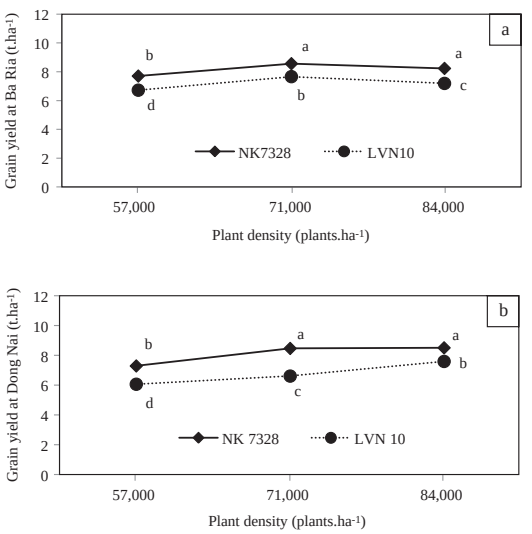

Figure 5 Effects of plant density on grain yield of two maize hybrids at: (a) Ba Ria; (b) Dong Nai. Means with different letters are significantly different at $P < 0.05$.

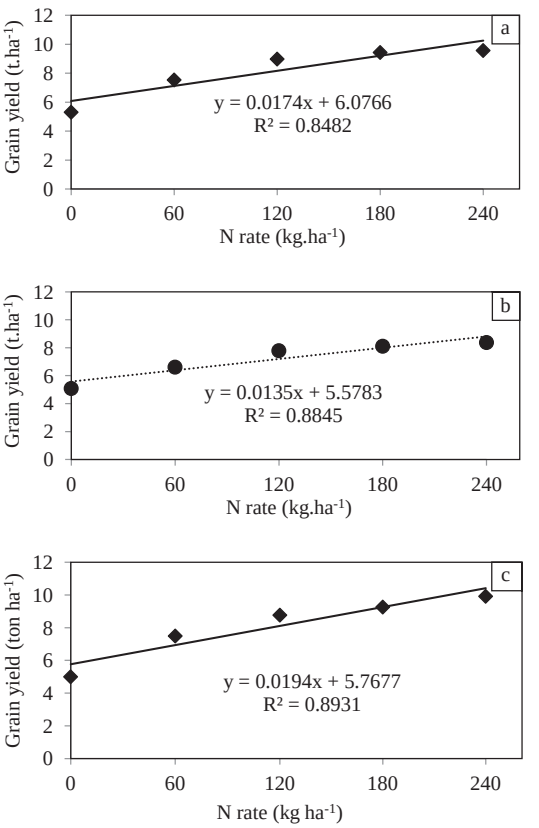

Figure 6 Effect of N fertilizer rate on grain yield of two maize hybrids at Dong Nai and Ba Ria. (R^2 = Correlation coefficient.); (a) NK7328 at Ba Ria; (b) LVN10 at Ba Ria; (c) NK7328 at Dong Nai.

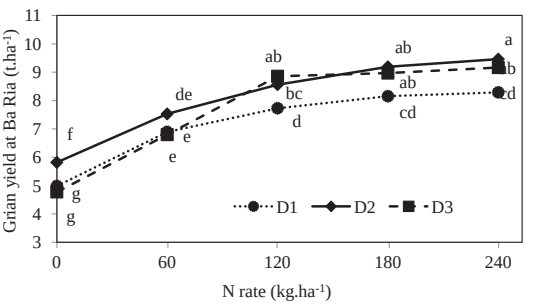

Figure 7 Interaction effects of plant density and N fertilizer rate on grain yield at Ba Ria. Means with different letters are significantly different at $P < 0.05$. (D1 = 57,000 plants.ha^{-1}; D2 = 71,000 plants.ha^{-1}; D3 = 84,000 plants.ha^{-1}.)

This indicated that a fertilizer rate at 120 kg.ha^{-1} of N was optimal for the maize hybrids to produce a higher grain yield. The three-way interaction effects of maize hybrid × plant density × N fertilizer rate were not significant for the maize grain yield at both locations (Table 7).

Grain yield components

Plant density and the N fertilizer rate had a significant effect on the number of kernels per ear and the kernel weight at both locations (Table 4). The number of kernels per ear and the kernel weight decreased with an increasing PD from 57,000 to 84,000 plants.ha^{-1}. The maximum PD produced the lowest numbers of kernels per ear. In addition, a higher plant density produced a higher number of ears per area but lowered the number of kernels per ear. Consequently, a high PD yielded a greater grain yield per unit area. These results were consistent with the reports by Lemcoff and Loomis (1994) and Bavec and Bavec (2002). In contrast, with an increasing N fertilizer rate, the numbers of kernels per ear and the kernel weight increased which was consistent with Melchiori and Caviglia (2008). There was also an interaction effect of hybrid and PD on the number of kernels per ear and the kernel weight (Table 5). Both hybrids recorded the highest number of kernels per ear and the highest kernel weight at the lowest PD.

A significant interaction effect of PD and the N fertilizer rate for the 1,000-kernel weight was observed at both locations (Figures 8a and 8b). These results indicated that N applied at 180 kg. ha^{-1} was sufficient for the maize plants to produce the maximum kernel weight under low and medium plant densities. The three-way interaction effects of maize hybrid × plant density × N fertilizer rate were not significant for the maize grain yield components at both locations (Table 7).

Nitrogen use efficiency

The hybrid NK7328 gave a significantly higher value of NUE than LVN10 at the two locations. The plant density had no significant effect on the NUE at the three densities. This showed that increasing the plant density of the two maize hybrids generally failed to improve the NUE, whereas the N fertilizer rate influenced the NUE, and the NUE declined as the N fertilizer rate increased up to 180 kg.ha^{-1} of N (Table 4).

Table 5 Interaction effects of plant density and maize hybrid on grain yield and yield components at Ba Ria and Dong Nai during the wet season 2011 (April–August).

Hybrid	PD (plant ha^{-1})	Grain yield (ton ha^{-1})		No. of kernel ear^{-1}(No)		1,000-kernel Wt. (g)	
		BR	DN	BR	DN	BR	DN
NK7328	57,000	7.65^{b}	7.25^{b}	461.50^{a}	446.00	329.60^{b}	305.00^{a}
	71,000	8.51^{a}	8.42^{a}	440.30^{b}	436.00	314.10^{c}	295.80^{b}
	84,000	8.18^{a}	8.46^{a}	426.80^{c}	412.60	303.50^{d}	287.30^{c}
LVN10	57,000	6.68^{d}	6.03^{d}	440.70^{b}	409.20	330.60^{a}	262.40^{d}
	71,000	7.61^{b}	6.57^{c}	405.50^{d}	417.00	299.60^{e}	256.40^{e}
	84,000	7.19^{c}	7.56^{b}	368.50^{e}	388.10	289.70^{f}	252.70^{e}
$LSD_{0.05}$		0.40*	0.43*	11.50**	n.s.	3.30**	3.50**
CV (%)		6.20	11.60	6.80	6.50	2.30	2.40

BR = Ba Ria; DN = Dong Nai.

$LSD_{0.05}$ = Least significant difference at 0.05 level.

n.s. = Not significant. * = Significant at 0.05 probability level; ** = Significant at 0.01 probability level.

a–e = Mean values with different lowercase superscripts in a column are significantly different at $P < 0.05$.

CV = Coefficient of variation.

There was a significant interaction effect of maize hybrid and PD on the NUE at Dong Nai (Figure 9). The LVN10 hybrid planted at 71,000 plants.ha^{-1} produced the optimum NUE. Furthermore, the results also showed that the NUE was not associated with the maize grain yield.

CONCLUSION

Plant density influenced the growth parameters of the maize hybrids grown in the wet season. Increasing the plant density from 57,000 to 84,000 plants.ha^{-1} resulted in an increase in the grain yield per unit area but a decrease in number of kernels per ear and the 1,000-kernel weight. The grain yield of maize planted at 71,000 plants.ha^{-1} was greater than that obtained from 54,000 plants.ha^{-1}. A higher N fertilizer rate, (up to 180 kg.ha^{-1}) caused a higher grain yield, number of kernels per ear and 1,000-kernel weight.

The performance of the maize hybrid NK7328 was better than hybrid LVN10 in terms of the LAI, grain yield and NUE at both locations. NK7328 had a greater grain yield than LVN10 by approximately 16% at both locations. The NUE was affected by the N fertilizer rate but there was no effect from PD. The NUE declined when the N fertilizer rate increased from 60 to 180

Table 6 Balanced analysis of variance of three-way interaction for leaf area index (LAI) and grain yield at Ba Ria and Dong Nai.

Source of variation	DF	LAI		Grain yield	
		MS	Prob.	MS.	Prob.
Ba Ria					
H × PD × N	8	0.5485	0.251	0.2119	0.693
Error (c)	48	0.4118	0.500	0.3036	0.500
Total	89	0.6456		2.6916	
Dong Nai					
H × PD × N	8	0.7020	0.246	0.3945	0.353
Error (c)	48	0.5231	0.500	0.3454	0.500
Total	89	0.5262		3.0905	

DF = Degrees of freedom; MS = Mean square; Prob. = Probability.
H = Plant height; PD = Plant density; N = Nitrogen fertilizer application.

Table 7 Balanced analysis of variance of 3-way interaction for number of kernels per ear, 1,000-kernel weight and nitrogen use efficiency (NUE) at Ba Ria and Dong Nai.

Source of variation	DF	Number kernel ear^{-1}		1,000-kernel weight		NUE	
		MS.	Prob.	MS	Prob.	MS	Prob.
Ba Ria							
H × PD × N	8	412.628	0.124	190.704	0.081	18.7079	0.934
Error (c)	48	243.874	0.500	20.2068	0.500	63.3095	0.500
Total	89	3520.16		1186.31		127.004	
Dong Nai							
H × PD × N	8	662.548	0.071	107.608	0.062	44.5767	0.603
Error (c)	48	336.597	0.500	22.8529	0.500	58.2390	0.500
Total	89	4365.11		981.694		168.709	

DF = Degrees of freedom; MS = Mean square; Prob. = Probability.
H = Plant height; PD = Plant density; N = Nitrogen fertilizer application.

kg.ha^{-1}. Furthermore, the NUE was not associated with the maize grain yield. For the new maize hybrid (NK7328) and the old hybrid (LVN10), the optimum plant density and N fertilizer rate for maize growing under rainfed conditions in southern Vietnam were 71,000 plants.ha^{-1} and 120 kg.ha^{-1}, respectively. Moreover, more study is needed in a wide range of environments to confirm the results, particularly on those sites where different climatic conditions prevail since the research was limited to a one year study at two sites.

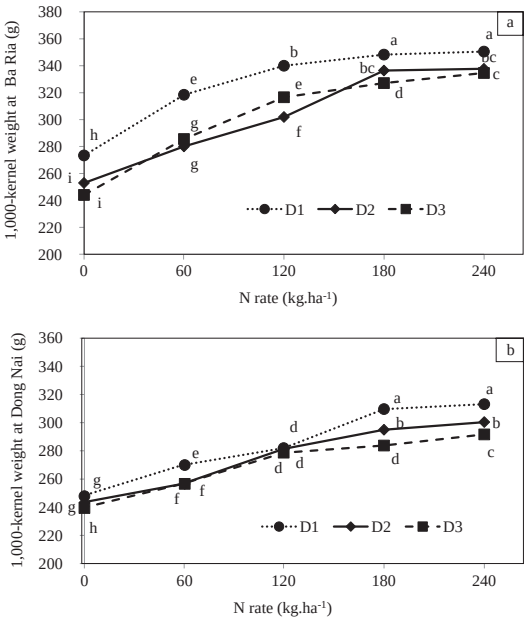

Figure 8 Interaction effects of plant density and N rate on 1,000-kernel weight at: (a) Ba Ria; (b) Dong Nai. Means with different letters are significantly different at $P < 0.05$. (D1 = 57,000 plants.ha^{-1}; D2 = 71,000 plants.ha^{-1}; D3 = 84,000 plants. ha^{-1}.)

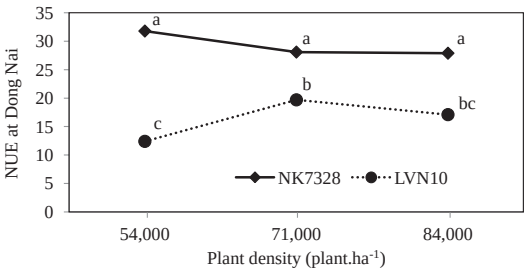

Figure 9 Interaction effects of maize hybrid and plant density on nitrogen use efficiency (NUE) at Dong Nai. Means with different letters are significantly different at $P < 0.05$.

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