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THESIS

PLANT DENSITIES AND NITROGEN FERTILIZER RATES AFFECT ON GROWTH, NITROGEN USE EFFICIENCY AND GRAIN YIELD OF DIFFERENT MAIZE HYBRIDS UNDER RAINFED CONDITION OF SOUTHERN VIETNAM

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Giang Hong Dinh 2014: Plant Densities and Nitrogen Fertilizer Rates Affect on Growth, Nitrogen Use Efficiency and Grain Yield of Different Maize Hybrids under Rainfed Condition of Southern Vietnam.
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Maize (*Zea mays* L.) is the one of the major food crops grown in Vietnam. The plant density (PD) and nitrogen (N) fertilizer are considered the most important crop management practices in improving maize grain yield. Two identical field experiments at Ba Ria and Dong Nai, were conducted in the wet season 2011 to study the effects of plant density and N rate on different maize hybrids. A split-split plot in RCB design was used and replicated three times. Two maize hybrids, NK7328 and LVN10, constituted the main plots and three PD (57,000, 71,000 and 84,000 plants ha^{-1}) were sub plots. Five N rates (0, 60, 120, 180 and 240 kg N ha^{-1}) were sub sub plots. The results revealed that NK7328 had greater LAI at Ba Ria and Dong Nai than LVN10. It also had greater grain yield than LVN10 at both locations (8.16 vs 7.19 and 8.09 vs 6.76 tons ha^{-1}, respectively). This greater grain yield was attributed to greater kernel number ear^{-1} and kernel weight. Considering nitrogen use efficiency (NUE), NK7328 exhibited higher NUE than LVN10. Increased PD from 57,000 to 84,000 plants ha^{-1} and N rate from 0 to 180 kg N ha^{-1} increased anthesis-silking interval (ASI) and leaf area index (LAI). Grain yield, number of kernel ear^{-1} and 1,000-kernel weight decreased with the increase in PD and vice versa with N rate. NUE of maize hybrid was significantly affected by N fertilizer rate but PD did not. The highest NUE was not associated with the greatest maize grain yield. The optimum plant density and N rate were 71,000 plants ha^{-1} or 70 × 20 cm spacing and 120-180 kg N ha^{-1} to be applied for maize production under rainfed condition in the southern Vietnam.

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Student's signature Thesis Advisor's signature

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LIST OF ABBREVIATIONS

ANOVA	=	Analysis of variance
ASI	=	Anthesis-silking interval
BR	=	Ba Ria
DN	=	Dong Nai
CV	=	Coefficient of variance
DAP	=	Days after planting
LAI	=	Leaf area index
N	=	Nitrogen
NUE	=	Nitrogen use efficiency
PD	=	Plant density
SK	=	Silking
TS	=	Tasseling
VE	=	Vegetative growth stage when emergence of the shoot from the soil.
V1	=	Vegetative growth stage when the lowest leaf has a visible collar. This leaf has a rounded tip.
VT	=	Vegetative growth stage when the lowest branch of the tassel is visible, but the silks have not emerged.
R1	=	Reproductive growth stage when any silk is visible.
R3	=	Reproductive growth stage when kernels are yellow with milky white fluid.
R6	=	Reproductive growth stage at physiological maturity when the milk line is no longer visible; a black layer forms at the kernel’s attachment, which signifies the end of dry matter accumulation.

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PLANT DENSITIES AND NITROGEN FERTILIZER RATES AFFECT ON GROWTH, NITROGEN USE EFFICIENCY AND GRAIN YIELD OF DIFFERENT MAIZE HYBRIDS UNDER RAINFED CONDITION OF SOUTHERN VIETNAM

INTRODUCTION

Maize (*Zea mays* L.) is the one of the major food crops grown in Vietnam and is cultivated in diverse environments. It is the substitute staple in the periods of rice shortage, especially for people in the rural areas and mountainous regions. Maize is also the primary source of feed for Vietnam's poultry and livestock industry (Ha *et al*., 2004). Although maize production increased rapidly to a total production of more than one million hectares in recent years, the overall productivity of maize has not been adequate to meet the increasing domestic demand. In the Southern region of Vietnam, maize was planted on around 0.3 million hectares with total production of more than 1.6 million tons mainly in the upland rainfed cropping system (General Statistical Office, 2010). However, the average national yield is only 4.1 tons ha^{-1}, far below potential yield of commercial maize hybrid. Besides, knowledge on yield potential, exploitable yield gaps, farming practices and constraints to improving productivity at the field level is still limited.

Plant density is considered one of the most important crop management practices and is accorded a high research priority. Duvick (2005) concluded that yield potential per plant has not increased over the years. Increasing yielding ability of newer maize hybrid is owed primarily to the increase in stress tolerance that in turn providing tolerance to higher plant densities. Westgate *et al*. (1997) reported that average grain yield of maize has increased steadily in recent years. Among other agricultural management practices, increased plant density and decreased row spacing have both contributed to increase grain yield per unit area. Witt *et al*. (2006) concluded that plant populations of 65,000 to 75,000 plants ha^{-1} are required to

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achieve high yields under favorable conditions in tropical Asia and in the drought-prone areas the plant populations must be lower than that. On the contrary, Tokatlidis *et al.* (2005) evaluated six hybrids and concluded that the highest grain yield was recorded at high density of 8.3 plants m^{-2} for all hybrids.

There have been many studies to determine the effect of nitrogen fertilizer on growth and production of maize. However, there is no single recommendation for all environmental factors as well as controlled factors such as soil fertility, hybrid selection, weather and cropping practices. Among plant nutrients, nitrogen (N) is the most important and essential for growing crops. Alam *et al*. (2003) reported the grain yield increased progressively with added nitrogen fertilizer up to 180 kg N ha^{-1}, but slightly reduced in grain yield with 220 kg N ha^{-1}. Pokharel *et al*. (2008) found that grain yield of maize increases with increasing nitrogen levels. The highest yield was obtained at 180 kg N ha^{-1}, and increased of 59 % over control. Yukui *et al*. (2009) concluded the biomass yield obtained from the nitrogen rate of 225 kg ha^{-1} was 11.7% higher than at 450 kg N ha^{-1}. Besides, the efficient use of nitrogen is an importance goal in maximizing yield while it has a minimal impact on the environment. On the other hand, the nitrogen use efficiency (NUE) among maize hybrids showed significantly different by amount of nitrogen supply and variation in utilization of accumulated and uptake efficiency (Moll *et al*., 1982). Excessive nitrogen fertilizer may results in low NUE and potentially harm to the environment. Rahmati (2009) concluded that increasing nitrogen application rate decreased nitrogen use efficiency. Hokmalipour *et al*. (2010) revealed that NUE was higher at 60 kg N ha^{-1} than 120 kg N ha^{-1}. De Juan Valero *et al*. (2005) suggested that the pattern of NUE values decreased with increasing fertilizer rates.

Very few researches have been conducted to evaluate the response of modern hybrid to various plant densities and nitrogen fertilizer application in Vietnam in recent years. At present in Vietnam, diverse maize genotypes, i.e. single cross, double cross and three ways hybrids are being grown. These genotypes respond differently to various ecology and management practices. The result from Hao and Hai (2008) indicated that the higher yield was obtained at plant density of 70,000 to 80,000 plants

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ha^{-1} with row spacing of 50 cm. According to Witt *et al*. (2006) maize grower probably need to adjust both timing and amount of fertilizer N, P, and K, and use split applications to better match crop demand for nutrients to increase yield and profitability. Similarly, Quy *et al*. (2008) reported that maize production strategy in Vietnam for 2020 requires intensive establishing crop management and site specific nutrient management for each hybrid, with lower cost of production for each region.

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OBJECTIVES

The objectives of this study were to determine suitable nitrogen application rates and optimum plant densities for each maize hybrid grown under rainfed condition in the southern Vietnam. The specific objectives were as follows:

1. To assess the effect of plant densities and nitrogen fertilizer rates on growth of maize.

2. To evaluate the performance of two maize hybrids as affected by different growing conditions.

3. To identify a more efficient nitrogen use and plant density for different maize hybrid under rainfed condition.

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LITERATURE REVIEW

1. Plant Density

Modern maize varieties mostly do not produce tiller, even at low plant densities, and usually produce one ear plant^{-1}. Therefore grain yield of maize was more sensitive to plant density because both leaf area and number of ear area^{-1} increase or decrease according to density (Gardner *et al.*, 1985).

The environment also influences the optimum plant density for yield. The primary environmental factors include irradiation, moisture, and soil fertility. Limitation of these environmental factors lowers the optimum plant density for maximum production (Gardner *et al*., 1985). The information on suitable plant population for each maize cultivar is one of the key factors for planning maize production (Bavec and Bavec, 2002). Westgate *et al*. (1997) reported that average grain yield of maize has increased steadily in recent years. Among other agricultural management practices, increased plant density and decreased row spacing both have contributed to increase grain yield per area. At lower than maximum yield population, adding more plants compensates for the lowered grain yield plant^{-1} due to the increased crowding. Above some population, however, the effect of rapidly increasing crowding due to the closer plant spacing cannot be offset by the yield of the added plants. Consequently, grain yield area^{-1} beyond this point decreases as a consequence of the sharp reduction in kernel number and kernel size produced per plant (Lemcoff and Loomis, 1994).

1.1 Effect on Growth and Growth Components

Leaf area (LA) plays an important role in plant growth analysis. Leaf area development in annual, determinate crop (vegetative growth stops at flowering), as leaf area develops, radiation interception by leaves increase (Gardner *et al*., 1985). The concept of leaf area index (LAI) was first introduced by Watson (1947) and defined as the ratio of leaf area (one side only) to a given unit of land area. LAI is the

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component of crop growth analysis that accounts for the ability of the crop to capture light energy and is critical to the understanding the function of many crop management practices. Discussing factor that influences the leaf area of crop, Bavec and Bavec (2002) mentioned genotype, plant density, climate and soil fertility. Plant density remained the most important factor that influences crop growth and LAI.

A leaf area index of 3-5 is usually necessary for maximum dry matter production of most cultivated crops (Gardner *et al*., 1985). Numerous researchers have shown a direct relationship between leaf area index (LAI) and plant density. LAI increases linearly as the plant density increases, but the leaf area plant^{-1} decreases as the plant density increase (Begna, 1996). With increased plant density from 36,600 to 73,200 plants ha^{-1} the leaf area index was doubled from 2.8 to 5.6, indicating LAI was strongly affected by plant density (Lemcoff and Loomis, 1994). Plant density affected leaf area expansion of maize mainly through the effects on leaf appearance rates, and that these effects were closely related to density effects on plant growth rate per leaf appearance interval (Bos *et al*., 2000). The other result of Hokmalipour *et al.* (2010) also supported that increasing plant density decreased leaf appearance rate. Dehdashti and Riahinia (2008) found that increased plant population from 10.5 to 13.9 plants m^{-2} increased LAI and radiation interception (RI) on average by 0.205 and 0.89% for each 1 plant m^{-2}.

Maize hybrids differ in total leaf number, individual leaf area, vertical leaf angle, and leaf area density distribution along the main stem (Maddonni and Otegui, 1996). The leaf area of two contrasting maize hybrids (leafy and non-leafy) were decreased significantly the individual plant of plant population increased from 75,000 to 90,000 plants ha^{-1} (Subedi *et al*., 2006). On the contrary, Malaviarachchi *et al*. (2007) showed that there was a steady increase in the LAI with plant density in every season because there were no significant variations in leaf area plant^{-1} with the different density levels. Although under medium N, low and intermediate plant density treatments resulted in larger leaves than high plant density treatment. Overall LAI was greater at the highest density than that at the low and medium plant densities (Ciampitti and Vyn, 2011). Furthermore, the increment in LAI provides more

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effective light interception (Tollenaar *et al*., 1997). This also promotes improved radiation use efficiency during grain filling, which further contributes to the production of more kernels plant^{-1} and higher grain yield (Tollenaar *et al*., 1992).

Sangoi *et al*. (2002) evaluated the response to the plant density of three hybrids commercially released during 1970s-1990s. They revealed that the increase in plant density from 2.5 to 10 plants m^{-2} increased barrenness, lengthened the anthesis-to-silking interval and decreased kernel set ear^{-1}. The increases in anthesis-to-silking interval for each 10,000 added plant ha^{-1} were 0.96 to 1.02 days for the two older hybrids and 0.79 days for the newer hybrid. Similarly, Tokatlidis *et al*. (2005) also concluded that the number of days from sowing to pollen shedding and ear silking, pollen-to-silking interval, and grain moisture at harvest decreased with decreasing plant density.

In maize, the height of the final plant, diameter of its stem is strongly influenced by environmental conditions during stem elongation. Temperature and photoperiod may influence stalk height by affecting the number of internodes (Duncan, 1975). Thus, plants that grow within a dense canopy under high plant density receive a different quality of light, enriched with far red (FR) and impoverished in red (R) radiation. This high FR/R ratio trigged many morphological changes in plant architecture, stimulating stem elongation, favoring apical dominance and decrease in stem diameter (Rajcan and Swanton, 2001). In addition, Ma *et al*. (2003) reported that plant density often showed significant effect on shoot. Total shoot dry matter was slightly greater at high density than at the low density treatment.

Gardner *et al*. (1985) quoted that increase plant density usually causes plants and stems to become smaller, weaker and often taller. Ogunlela *et al*. (1988) concluded that increasing maize plant density increased plant height and ear height, up to 75,000 plants ha^{-1}. Other result from Sangoi and Salvador (1998) indicated that plant height was significantly influenced by the single effect of cultivars and plant density. Averaged of five genotypes, each increase in 25,000 plants ha^{-1} promoted an increase of 2.7 cm in plant height. Sani *et al*. (2008) reported that plant density effects

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on plant height at the vegetative stage. The tallest plants were recorded at 82 days after sowing (DAS) with plant density of 66,000 plants ha^{-1} compared with other plant density of 53,000 and 38,000 plants ha^{-1}. The plant might have used assimilates in bringing about increase in height to attempt to reach for more sunlight. On the contrary, Boomsma *et al*. (2009) revealed that plant height of maize at flowering stage (R1) often declined with an increase plant density from 54,000 plants ha^{-1} to 79,000 plants ha^{-1} or suboptimal 104,000 plants ha^{-1}.

1.2 Grain Yield and Yield Components

Grain yield of maize hybrids differ in their response to plant density and little is known about the yield components underlying these differences (Echarte *et al*., 2000). Maize grain yield increases with planting density to some maximum value and then decline. The plant density that produces a maximum yield varies with varieties, environment, fertility and planting pattern. For a given hybrid, the yield of maize generally increases as density is raised until one or more factor such as water supply, available plant nutrients and others become limiting.

According to Tokatlidis *et al*. (2010), maize grain yield $plant^{-1}$ increased significantly with decreasing plant density and potential yield $plant^{-1}$ was mostly expressed at ultra-low density (0.74 plant m^{-2}). Bavec and Bavec (2002) concluded that cob characters (i.e. 1,000-kernel weight, cob length, number of kernel rows and number of kernels row^{-1}) decreased significantly by increasing plant population from 4.5 to 13.5 plants m^{-2}, and higher grain yield can be achieved by increasing plant population from 9 to 13 plants m^{-2} that depend on older or newer cultivars. Contrarily, Paponov *et al.* (2005) revealed that two hybrids different in NUE, the yield increased with increasing plant density from 5 to 15 plants m^{-2}. Tokatlidis *et al.* (2005) showed that the number of ear $plant^{-1}$, ear length, and grain protein concentration increased with decreasing plant density from 8.3 to 2.5 plants m^{-2}, the highest grain yield obtained at high density of 8.3 plants m^{-2}.

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Dehdashti and Riahinia (2008) found that grain yield increased by increasing plant population from 10.5 to 13.9 plants m^{-2}, furthermore grain yield increase 222.7 kg ha^{-1} for each 1 plant m^{-2} added. Conversely, Arif *et al*. (2010) showed that higher grain weight of 33.2 g was recorded for 7.5 plants m^{-2} while minimum grain weight of 30.4 g for the highest plant population of 9 plants m^{-2}. Rahmati (2009) reported that there was a significant effect on seed yield due to different density among 6.5, 7 and 7.5 plants m^{-2}. Increasing plant density increased seed yield and dry matter yield due to increasing ear number and plant number m^{-2}. Echarte *et al*. (2000) found grain yield response to plant density to be positively and strongly related to number of kernel m^{-2} and negatively and weakly related to weight $kernel^{-1}$. Increasing in plant density from 5 to 14.5 plants m^{-2} increased kernel number m^{-2} by 38 to 56% and decreased kernel weight from 6 to 17 %.

2. Nitrogen Rate

The demand for N is determined by the growth rate and the nitrogen composition of the new tissues. In the field, both growth rate and tissue composition will vary with nitrogen and water supply, plant competition and other environmental factors. The maximum demand for N will be achieved under non-limiting conditions for photosynthesis when growth rate approaches its genetic potential (Nova and Loomis, 1981). Among plant nutrients, N is the most important and essential for growing crops. N is a component of amino acids, nucleoproteins, amides and is essential to cell division, expansion, and therefore growth (Gardner *et al*., 1985).

2.1 Effect on Growth and Growth Components

D’Andrea *et al*. (2008) demonstrated that N availability was primarily affected on the pattern of biomass allocation between vegetative and reproductive organ of some hybrids, due to N concentration was far more stable in the ear rather than in the rest of the plant. Muchow (1988) concluded that radiation use efficiency was responsive to nitrogen supply and increased with higher rates of nitrogen applied; the radiation use efficiency declined during grain filling.

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Ogunlela *et al*. (1988) revealed that ear diameter, kernel depth, number of ear plant^{-1}, plant height and dry matter production increased by increasing N rates from 0 to 200 kg N ha^{-1} while number of days to tasseling declined. Likewise, Boomsma *et al.* (2009) found that plant height of maize at flowering stage (R1) increased significantly with the increase in N rates from 0 to 165 kg N ha^{-1} but was not observed when increasing from 165 to 330 kg N ha^{-1}. Yukui *et al*. (2009) reported that plant height and stem perimeter is adversely affected by excessive application of N fertilizer.

On the contrary, the time from anthesis until maximum grain size was longer and increased with increasing N supply Muchow (1988). Ding *et al.* (2005) found that there was no significant difference in harvest index and leaf area at flowering between the N-deficient (0 kg N ha^{-1}) and control (195 kg N ha^{-1}) of six maize hybrids in experiment. Hokmalipour *et al.* (2010) reported that increasing N level increased leaf appearance rate. Lemcoff and Loomis (1994) reported that N stress reduced whole plant N concentration and leaf area. However, phenology and aboveground dry matter plant^{-1} at silking was not affected. De Juan Valero *et al.* (2005) also supported that differences of grain yield among nitrogen levels were mainly due to a significant variation in maximum LAI, leaf area duration and crop growth rate. On the contrary, Vos *et al.* (2005) reported that N supply did not affect to the leaf appearance rate and the duration of leaf expansion.

Sangoi *et al.* (2001) reported that under higher rates of nitrogen fertilizer, the old hybrids Ag 12 and Ag 28 took up more N and presented higher values of shoot dry matter at maturity compared with new hybrid Ag 9012. Nonetheless, they set less grain ear^{-1} which contributed to decrease their grain yield and NUE. De Juan Valero *et al.* (2005) suggested that decreasing pattern in NUE values with increasing N fertilizer rates. Likewise, Rahmati (2009) concluded increasing nitrogen application rates decreased NUE. Furthermore, Boomsma *et al.* (2009) quoted that the selection of hybrids with the combination of high NUE and stress tolerance to low N is even more challenging when maize plant densities are greater than optimum.

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Paponov *et al.* (2005) found that increasing the rate of N supply at sowing increased grain yield plant^{-1} and kernel weight in both maize genotypes. Setiyono *et al.* (2010) suggested that N accumulation in the above ground plant dry matter was 232 kg N ha^{-1} at the average yield of 12 tons ha^{-1}.

2.2 Effect on Grain Yield and Yield Components

Increased N levels are known to cause significantly favorable influence on the yield attributes of maize. Paponov *et al.* (2005) noticed that yield formation of maize was strongly limited by N supply, and kernel weight linearly decreased with decreasing N uptake. Muchow (1994) reported that there was no significant relationship between grain yield and N uptake at maturity where 24 g N m^{-2} was applied. Gehl *et al*. (2005) observed the average grain yield of maize ranged from 3.6 to 11.8 tons ha^{-1}, and maximum grain yield was achieved with split application of 185 kg N ha^{-1}.

Muchow (1988) reported that the rate of grain yield accumulation was more responsive to N supply, the grain yield at maturity ranged from 205 to 865 g m^{-2} as N supply increased from 0 to 42 g m^{-2}. Boomsma and Vyn (2007) concluded that the availability of N is more critical for maintaining grain yield area^{-1} at higher plant populations than at lower plant populations. Limitations in available N lead to reduced foliar N concentrations and earlier leaf senescence that limit grain yield plant^{-1}.

The results from Ma *et al*. (2003) showed that N supply at 60, 80 and 180 kg N ha^{-1} resulted in better grain yield than without N fertilizer, but did not differ significantly in grain yield between each other. This could be attributed to a high initial soil mineral N level. Alam *et al*. (2003) reported that grain yield increased progressively with added nitrogen fertilizer up to 180 kg N ha^{-1}. The maximum grain yield was 5.03 tons ha^{-1}, but slightly reduced in grain yield at 220 kg N ha^{-1}. Increasing grain yield was mainly due to higher number of kernel ear^{-1}. De Juan Valero *et al*.

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(2005) evaluated the effect of various doses of N at the rate of 0, 130, 150, 175 and 300 kg N ha^{-1} on maize during three-years of field experiment 1999–2001. They reported that there were no grain yield differences among fertilizer treatments in 1999. The highest grain yield (16.70 tons ha^{-1}) was recorded with the highest N fertilizer treatment (300 kg N ha^{-1}) in 2001.

Kien *et al.* (2008) concluded that the highest economic efficiency of maize variety LVN10 was attained at the level of 240 kg N ha^{-1}. Areerak *et al.* (2008) reported that grain yield of drought tolerance maize hybrids increased significantly with increasing N apply. The best response of NS2 was observed at 125 kg N ha^{-1} whereas NSX042029 and NSX042022 responded at 187.5 kg N ha^{-1}. Similarly, Pokharel *et al.* (2008) found that grain yield of maize increased with increasing N levels from 30 to 210 kg N ha^{-1}. The highest grain yield was obtained at 180 kg N ha^{-1}, an increase of 59 % over control.

Melchiori and Caviglia (2008) conducted two field experiments in 2002-2004 to evaluate the effect of N supply on two maize hybrids. They concluded the increased in kernel number (KN), kernel weight (KW) and grain yield in both seasons for the optimum planting date with increasing N supply. Rahmati (2009) reported that the number of seed ear^{-1}, seed yield, dry matter and productivity degree were increased by increasing N rate. The maximum seed yield was obtained at N rate of 240 kg N ha^{-1}. However, there was no significant difference between 200 and 240 kg N ha^{-1} in seed yield.

Arif *et al*. (2010) reported that grain row^{-1}, grain ear^{-1}, grain and biological yield of maize increased significantly with increasing N levels from 80 to 120 kg N ha^{-1}. Hokmalipour *et al*. (2010) showed that increase N application led to the increase in grain yield, number of grain row^{-1}, number of rows ear^{-1} and number of grain ear^{-1}.

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MATERIALS AND METHODS

Two identical experiments were conducted at Syngenta satellite farms in Da Bac, Chau Duc, Ba Ria province and Bao Hoa, Xuan Loc, Dong Nai province during the wet season 2011 from April to August. Both locations are the major maize production area in the wet season in the Southern Vietnam.

1. Materials

1.1 Plant materials:

Maize hybrids NK7328 and LVN10 were used in these experiments. Two hybrids had the same relative maturity (105 days), and commercially important for this area. NK7328 was developed by Syngenta AG in Thailand and released to the market in 2011. LVN10 was created by Vietnam Maize Research Institute and has been used since 1995 as a national maize hybrid check for governmental trial.

1.2 Equipment

(1) Soil sampling and soil analysis materials
(2) Electronic balance, moisture meter
(3) Wire tags, plastic and paper bags, nylon mesh bags
(4) Harvesting and yield data collection material

1.3 Chemicals

(1) Urea fertilizer (46% N)
(2) Phosphorus fertilizer (16% P_2O_5)
(3) Potassium fertilizer (60% K_2O)

2. Methods

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2.1 Experimental design

Each experiment was laid out in a split-split plot in randomized complete block (RCB) design with three replications. Treatments included combinations of two maize hybrids, three plant densities and five N rates. Two hybrids were allocated in the main plots. Three plant densities (PD): 70 cm × 25 cm (57,000 plants ha^{-1}), 70 cm × 20 cm (71,000 plants ha^{-1}) and 70 cm × 17 cm (84,000 plants ha^{-1}) were randomly assigned in sub-plots. The plant density of 57,000 plants ha^{-1} was typically farmer practice, 71,000 plants ha^{-1} was recommended by the seed companies and 84,000 plants ha^{-1} considered as high plant density. N fertilizer rates consisted of 0 (control), 60, 120, 180 and 240 kg N ha^{-1} were applied in the sub-sub-plots. N fertilizer rates that farmers use ranged from 120 kg to 240 kg N ha^{-1} depend on locations and seasons. The individual plot size was 4.2 m in width and 5 m in length. In each sub-sub-plot six rows of maize hybrid were planted.

2.2 Cultural practices

In all treatments, plots were hand-planted at three seeds per hill and thinned to the desired plant population of 57,000 plants ha^{-1}, 71,000 and 84,000 plants ha^{-1} at three-leaf (V3) stage. For the basal fertilizer application, 90 kg P ha^{-1} as single super phosphate and 90 kg K ha^{-1} as muriatic potash were applied in all sub-sub-plot. After the first 15 and 30 days of plant growth, five N treatments were supplied manually in the form of urea (46% N) according to treatments. Weeds were controlled by the atrazine pre-emergence herbicide and hand-weeded as recommended in the southern Vietnam and also farmer practice. The crop was protected against insects and other pests through one time of insecticide application.

2.3 Soil sampling

Just before starting of the experiments, soil samples from the experimental sites were collected to determine the nutrient content in the soil. After corn harvest at the end of the experiments, nutrient balance of soil from experimental sites was

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measured to compare with its initial levels. Soil samples were analyzed at the Soil Science Analysis Department, Southern Institute of Science and Technology Agriculture. The result of experimental soil analysis was shown in table 1.

Table 1 Some soil properties at the experimental sites at Ba Ria and Dong Nai.

Expt. Site	Chemical analysis					
	pH(H_2O)	Organic matter (%)	N content (%)	P (mg/kg) Bray 2	K (mg/kg)	Ca (mg/kg)
Ba Ria	5.3	3.51	0.17	20	94	0.64
Dong Nai	6.3	1.79	0.12	75	102	0.95

The previous crop of the experiment was mungbean and maize at Ba Ria and Dong Nai, respectively.

2.4 Climatic data collection

Climatic data for the period of five years were collected at two locations Ba Ria and Dong Nai where the experiments were carried out. The monthly detail data of precipitation (mm), maximum temperature (^oC) and minimum temperature (^oC) were shown in figures 1 and 2.

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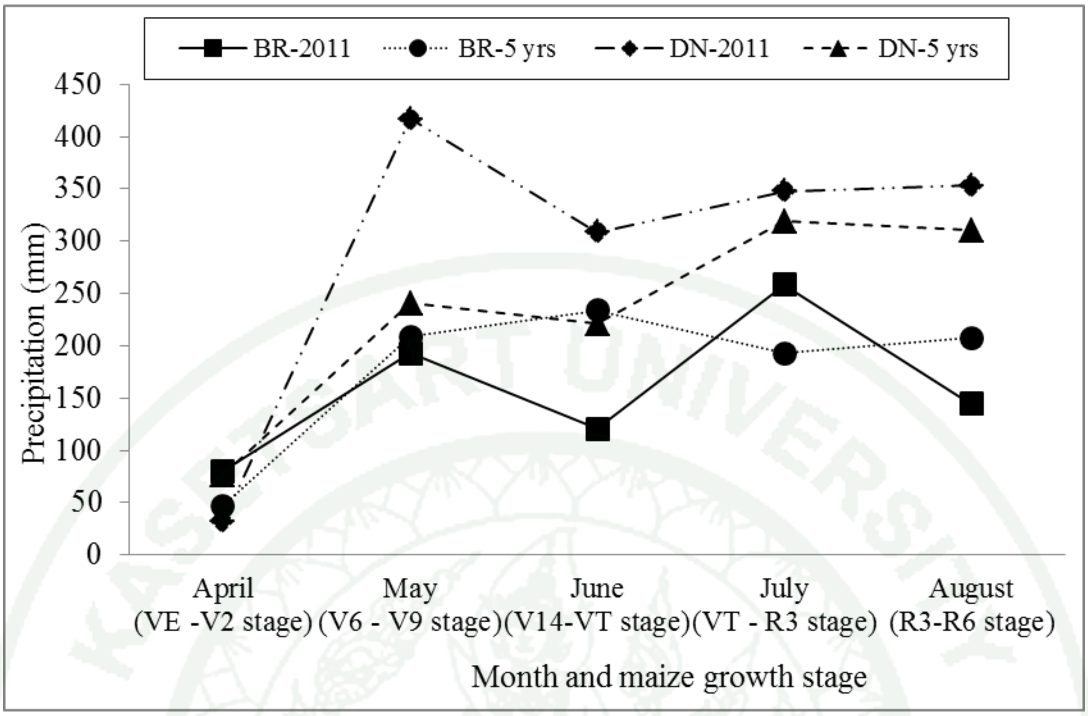

Figure 1 Monthly precipitation data during maize crop growing year 2011 and the mean of the past 5 years (2006-2010): BR-2011= Ba Ria 2011; DN-2011 = Dong Nai 2011; BR-5 yrs = Ba Ria mean in 5 years; DN-5 yrs = Dong Nai mean in 5 years.

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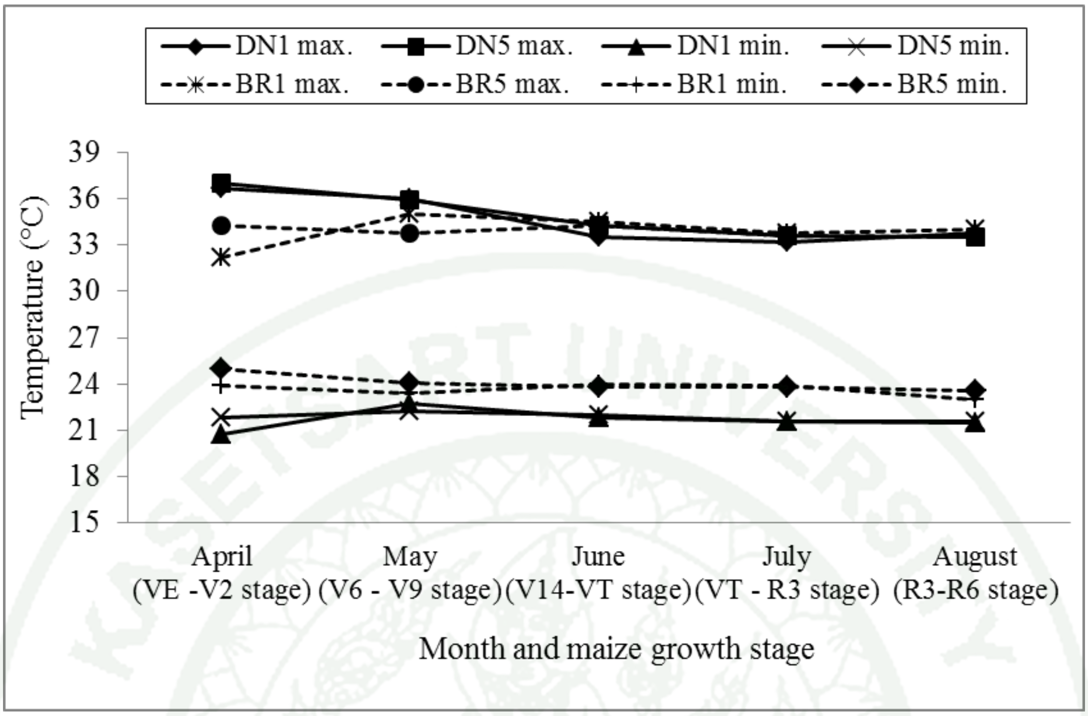

Figure 2 Monthly temperature (temp) data during maize crop growing year 2011 and the mean of the past 5 years (2006-2010): DN1 max. = Dong Nai maximum temp; DN1 min. = Dong Nai minimum temp; DN5 min. = Dong Nai maximum temp mean 5 years; DN5 max. = Dong Nai minimum temp mean 5 years; BR1 max. = Ba Ria maximum temp; BR1 min. = Ba Ria minimum temp; BR5 min. = Ba Ria maximum temp mean 5 years; BR5 max. = Ba Ria minimum temp mean 5 years.

2.5 Data collection

(1) Tasseling and silking dates

The dates were recorded when 50% of tassel was shedding and 50% of silk was visible, respectively.

(2) Plant height and ear height (cm)

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The plant height was measured from the base of the plant to the collar of flag leaf and expressed in centimeters. The ear height was measured from the base of the plant to the node bearing the upper ear.

(3) Leaf area and leaf area index

The data were recorded at seven leaves (V7) stage and beginning of tasseling (VT) stage. At V5, three randomly successive plants were tagged in the central row of each plot. Tags were placed between leaves 5 and 6, which allowed the identification of individual leaves and total leaf number qualification. The numbers of senesced leaves were recorded fortnightly, with a leaf considered senesced when half or more of its area turned yellowed.

Leaf length (L) and maximum leaf width (W) were registered and used to calculate leaf area (A) as in Montgomery (1911, Eq. (2)):

$$\text{Leaf area (A)} = \alpha \times L \times W \qquad \text{Where } \alpha = 0.75$$

$$\text{Leaf area index (LAI)} = \frac{A_L}{A_G}$$

Where A_L is the leaf area plant^{-1} (cm^2) and A_G is the land area plant^{-1} (cm^2).

(4) Nitrogen use efficiency (NUE)

For each sub-sub plot receiving side-dress N application at both locations, NUE was calculated as the ratio of incremental grain yield response (N fertilized–unfertilized) to the N fertilizer applied (Cassman *et al.*, 2003). The following equation was used for the NUE calculation:

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$$NUE = \frac{GY_{fert.} - GY_{unfert.}}{N\ applied}$$

Where $GY_{fert.}$ is the per-unit-area grain yield (kg ha^{-1} at 15.5% moisture) of a treatment receiving Nitrogen (kg ha^{-1}), and $GY_{unfert.}$ is the per-unit-area grain yield of the treatment without applied N treatment. N applied is the amount of applied nitrogen (kg ha^{-1}).

(5) Grain yield (ton ha^{-1})

When plants reach physiological maturity, the ears from two inner rows were harvested. Ears were separated, air dried, shelled, cleaned and weighed. The grain yield was adjusted to 15.5% moisture content and expressed in ton ha^{-1}.

Ear samples of five randomly selected plants in each plot were taken at harvesting time to estimate for the following characters.

(6) Ear length

Length of the cob was measured from the base to the tip of the cob and expressed in centimeters (cm).

(7) Number of kernel rows ear^{-1}

The average number of kernel rows ear^{-1} was obtained by counting the total rows from all the observational ears and dividing them by number of ears.

(8) The 1,000-kernel weight

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Kernel from sampled ear at harvest was counted and weighed to determine 1,000-kernels weight. The 1,000-kernel weight was adjusted to 15.5% moisture content and expressed in gram.

(9) Number of kernel ear^{-1}

Number of kernel ear^{-1} was calculated from the kernel weight ear^{-1} and the corresponding thousand kernel weight as follows:

$$\text{Number of kernel ear}^{-1} = \frac{\text{Kernel weight ear}^{-1}\text{ (g)}}{\text{Weight of 1,000 kernels (g)}} \times 1000$$

(10) Shelling percentage

After obtaining ear dry weight as well as kernel weight after shelling in each plot, the shelling percentage was calculated as follows:

$$\text{Shelling percentage} = \frac{\text{Kernel weight plot}^{-1}}{\text{Ear yield plot}^{-1}} \times 100$$

2.6 Statistical analysis

All resulted data were subjected to analysis of variance (ANOVA) appropriate for a split-split-plot in randomized complete block (RCB) design. Separate analysis of variance was done for each parameter. Treatment mean differences were tested using LSD test at $P < 0.05$. Correlations among parameters were analyzed using IRRISTAT version 5.0.

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RESULTS AND DISCUSSIONS

1. Plant growth parameters

In the rainy season 2011 there was good rainfall distribution from April to August at the both locations (Figure 1). The temperatures recorded for Ba Ria and Dong Nai during the course of the experiments were similar to their respective past 5-years average (Figure 2). This is typically a good combination in order to produce high yielding crops. Thus the maize plant received good growth condition throughout the growing season. Plant growth response of two maize hybrids NK7328 and LVN10 to N fertilizer rates were observed at the three arrangements of plant density in two locations. The stages of maize plant development were described according to the method of Ritchie e*t al.* (1996).

1.1 Days to 50% tasseling

The days to 50% tasseling, NK7328 maize hybrid had longer than LVN10 about 2.4 days (Table 2). Plant density and N fertilizer rates had a significant effect on number of days to tasseling at Ba Ria (Table 2). Plant tasseled earlier when N was applied at 180 and 240 kg N ha^{-1} (57.3 days after planting DAP) followed by 58.2 DAP for treatment of 120 kg N ha^{-1}. The latest tasseling was recorded about 59 DAP for two N rates of 0 kg and 60 kg N ha^{-1}. However, there was no significant difference in number of days to tasseling when increasing N rate from 0 kg to 60 kg N ha^{-1} and 180 to 240 kg N ha^{-1}. These findings were in general agreement with the result of Ogunlela *et al*. (1988), who found that increasing N rate from 0 up to 200 kg N ha^{-1} decreased the number of days to tasseling. Increasing plant density from 57,000 to 71,000 plants ha^{-1} delayed tasseling 0.6 day but the difference was not observed when increasing from 71,000 to 84,000 plants ha^{-1}.

Similarly, the NK7328 hybrid flowered at 57.7 DAP, which was 2.3 days later than LVN10 hybrid. N fertilizer rates shortened tasseling dates significantly at Dong Nai (Table 3). Maize plant receiving 120 kg N ha^{-1}, 180 kg N ha^{-1} and 240 kg N

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ha^{-1} flowered at 56 DAP, followed by 60 kg N ha^{-1} which flowered 56.9 DAP while the lowest N rate (0 kg N ha^{-1}) resulted in maize flowering at 57.4 DAP; 0.7 to 1.4 days later than the other treatments. Contrarily, plant density did not have any impact on tasseling date. Maize plants under the three densities flowered at round 56.2 DAP.

1.2 Days to 50% silking

At Ba Ria, the data showed significant difference in days to silking as affected by maize hybrid, plant density and N fertilizer rate (Table 2). NK7328 hybrid had the number of days to silking longer than LVN10 hybrid 1.6 days. The number of days to silking decreased when increasing N fertilizer rate. The lowest number of days to silking was 58.7 DAP for the higher N rate (240 kg N ha^{-1}) and 180 kg N ha^{-1} followed by N fertilizer rate of 120 kg N ha^{-1} (59.6 DAP) and 0 kg N ha^{-1} (61.4 DAP). The number of days to silking gradually increased with increasing plant density. The highest number of days to silking was 60.6 days at the maximum plant density of 84,000 plants ha^{-1}, followed by 60.3 days and 58.7 days for the plant density at 71,000 plants ha^{-1} and 57,000 plants ha^{-1}.

The trend for days to silking at Dong Nai was similar to that of Ba Ria (Table 3). Plant density and N fertilizer had a significant effect on days to silking of the maize hybird. NK7328 hybrid had days to silking 2 days longer than LVN10 hybrid. Higher N rate decreased days to silking. The highest N rate (240 kg N ha^{-1}) gave the lowest 57.1 days to silking. No increase in days to silking was observed with N rate of 180 kg ha^{-1}. There was also significant difference at each rate of N treatment where at 120 kg N ha^{-1}, 60 kg N ha^{-1} and 0 kg N ha^{-1} the days to silking were 57.4 days, 58.3 days and 59.3 days, respectively. The highest N rate had 2.2 days shorter than control treatment. Days to silking increased with increasing plant density. At the highest PD of 84,000 plant ha^{-1} accounted for 58.2 days to silking, followed by plant density of 71,000 and 57,000 plants ha^{-1}. In general, higher plant density seemed to delay silking and higher nitrogen applications accelerated silking. This result was particularly supported by Tokatlidis *et al*. (2005), who also concluded that the number of days from sowing to silking decreased with decreasing plant density.

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The maize hybrid NK7328 had shorter anthesis-silking interval (ASI) than LVN10 at the two locations (Tables 2 and 3). Plant density and N rate had a significant effect on ASI. Increasing plant density increased ASI in all observations. Contrarily, N fertilizer rates decreased the anthesis-silking interval but did not differ between N rates from 120 to 240 kg N ha^{-1}. The longest ASI was seen at the lowest N rate. Similar findings have been reported in the previous studies (Sangoi *et al*., 2002; Boomsma *et al*., 2009).

1.3 Plant height

At Ba Ria, plant density and N fertilizer rate affected significantly on plant height (Table 2). There was no significant difference plant height between two hybrids. Plant height of maize increased with increasing plant density. The highest plant density of 84,000 plants ha^{-1} produced the tallest plant at 229 cm. While, at plant density of 71,000 plants ha^{-1} and 57,000 plants ha^{-1} plant height were recorded 226.7 and 221.6 cm, respectively. The increase in N rate had significant influence on plant height. There was significantly difference in plant height among all N treatments. However, no significant increase in plant height was observed when N fertilizer rate increased from 180 kg N ha^{-1} to 240 kg N ha^{-1}. There was significant interaction effect of plant density and N rate on plant height. The tallest plant height of 239.2 cm was recorded at 240 kg N ha^{-1} and 84,000 plants ha^{-1} meanwhile without fertilizer rate the 71,000 plants ha^{-1} gave the shortest plant height of 212.8 cm.

Similar results were observed also at Dong Nai (Table 3). There were significant differences in plant height among different plant density. The tallest plant was recorded at the highest plant density of 84,000 plants ha^{-1}. Likewise, at the highest N rate plant height was 238 cm while the other four N treatments had the lower values. There was significant interaction effect of maize hybrid and N rate on plant height. The taller plant height was 237.9 cm to 239.8 cm observed at the highest N rate for both hybrids. Generally, the result shown in this study was consistent with the work of Ogunlela *et al*. (1988), Sangoi and Salvador (1998), Sani *et al.* (2008) and Boomsma *et al*. (2009).

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1.4 Ear height

At Ba Ria, the effect of maize hybrids, plant densities and nitrogen fertilizer rates on ear height was shown in Table 2. Ear height of NK7328 hybrids and LVN10 were the same. The ear height of maize increased with increasing plant density from 57,000 to 71,000 plants ha^{-1}. Meanwhile, there was no significant difference in ear height between plant density at 71,000 plants ha^{-1} and 84,000 plants ha^{-1}. Increase in N fertilizer rates had significant influence on ear height. There was significantly difference in ear height among all N treatments. However, no significant increase in ear height was observed when increasing N fertilizer rates from 180 to 240 kg N ha^{-1}. The maximum N fertilizer rate gave the highest ear height of 133.8 cm whereas treatment without N fertilizer produced shorter ear height 116.1 cm. There was significant interaction effect of plant density and N rate on ear height. The tallest ear height of 138.3 cm was recorded at 240 kg N and 84,000 plants ha^{-1} while without fertilizer rate and 57,000 plants ha^{-1} gave the shortest plant height of 113.3 cm.

The similar trend was observed for the effect of plant density and N fertilizer rate on ear height at Dong Nai (Table 3). The highest ear height was recorded at highest plant density of 84,000 plants ha^{-1}. Increasing N fertilizer rate resulted in the increase ear height. The ear height of 141 cm was recorded at 180 and 240 kg N ha^{-1} that was significant higher than other three N treatments (0, 60 and 120 kg N ha^{-1}). There was significant interaction effect of hybrid and N rate on ear height. The hybrid NK7328 gave the tallest ear height of 142 cm with N rate at 240 kg N ha^{-1}. In general, the effect of plant density and N rate on ear height agreed with Ogunlela *et al*. (1988). They concluded that ear height of maize increased with increasing plant density, up to 75,000 plants ha^{-1}.

1.5 Leaf area index

LAI at tasseling stage showed significantly different effect of hybrids, plant densities and N rates at Ba Ria and Dong Nai (Tables 2 and 3). NK728 exhibited greater LAI than LVN10 at both Ba Ria and Dong Nai (4.32 vs 3.92 and 4.31 vs 4.11,

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respectively). LAI increased linearly when plant density increased from 57,000 to 84,000 plants ha^{-1}. The maximum plant density resulted in the greatest LAI at two locations, 4.67 and 4.7 for Ba Ria and Dong Nai, respectively. In comparison, LAI increased respectively by 18 and 33% for the 71,000 and 84,000 plants ha^{-1} at Ba Ria, and by 18 and 29% for the same respective plant densities at Dong Nai. The increase in N fertilizer rates increased LAI linearly. The lowest LAI was observed at 0 N treatments and the highest at 240 kg N ha^{-1}. On the other hand, the data also indicated that no further improvement of LAI while N rates increased from 180 to 240 kg N ha^{-1}.

There was significant interaction effect of maize hybrid and plant density at both locations (Figure 3). NK7328 hybrid gave significantly higher LAI than LVN10 for three plant densities in Ba Ria but only at 57,000 plants ha^{-1} at Dong Nai. Even though the leaf area of individual plant often declined with each increment of plant density regardless of N rates (Boomsma *et al.*, 2009), these results indicated that the addition of more plant density compensated for declines in individual plant leaf area. There was also significant interaction effect of maize hybrid and N fertilizer rate (Figure 4) at two locations. LAI increased with increasing N rates for both hybrids. The highest LAI was recorded at N rate of 180 kg ha^{-1}.

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Table 2 Effects of plant densities and nitrogen fertilizer rates on days to tasseling 50% (TS), days to silking 50% (SK), anthesis-silking interval (ASI), plant height, ear height and leaf area index (LAI) at tasseling stage (VT) of two maize hybrids at Ba Ria during the wet season 2011 (Apr-Aug).

Hybrid	PD (plants ha^{-1})	N rate (kg ha^{-1})	TS (days)	SK (days)	ASI (days)	Plant height (cm)	Ear height (cm)	LAI
NK7328			59.4 a[§]	60.7 a	1.4 b	226.5	126.8	4.32 a
LVN10			57.0 b	59.1 b	2.1 a	225.1	125.5	3.92 b
$LSD_{0.05}$			0.3**	0.3**	0.2**	NS	NS	0.09**
	57,000		57.9 b	58.7 b	0.9 c	221.6 c	121.1 b	3.52 c
	71,000		58.5 a	60.3 a	1.8 b	226.7 b	128.7 a	4.17 b
	84,000		58.4 a	60.6 a	2.4 a	229.0 a	128.8 a	4.67 a
$LSD_{0.05}$			0.4*	0.3**	0.3**	1.9**	1.4**	0.11**
		0	59.1 a	61.4 a	2.3 a	215.6 d	116.1 d	3.23 d
		60	58.9 a	60.8 b	1.9 b	218.4 c	120.7 c	3.79 c
		120	58.2 b	59.6 c	1.5 c	227.7 b	127.6 b	4.32 b
		180	57.5 c	58.9 d	1.4 c	232.8 a	132.7 a	4.62 a
		240	57.3 c	58.7 d	1.4 c	234.4 a	133.8 a	4.65 a
$LSD_{0.05}$			0.5**	0.4**	0.3**	2.4**	1.8**	0.14**
CV(a) %			0.7	1.1	33.5	0.9	3.0	20.5
CV(b) %			1.0	1.0	30.3	1.4	2.6	10.3
CV(c) %			1.2	1.1	32.1	1.6	2.2	15.6

[§] In a column, means with different letters are significantly different at $P < 0.05$.

*, ** = Significant at $P < 0.05$ and $P < 0.01$, respectively.

NS = Non-significant at $P < 0.05$.

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Table 3 Effects of plant density and nitrogen fertilizer rates on days to tasseling 50% (TS), days to silking 50% (SK), anthesis-silking interval (ASI), plant height, ear height and leaf area index (LAI) at tasselling stage (VT) of two maize hybrids at Dong Nai during the wet season 2011 (Apr-Aug).

Hybrid	PD (plants ha^{-1})	N rate (kg ha^{-1})	TS (days)	SK (days)	ASI (days)	Plant height (cm)	Ear height (cm)	LAI
NK7328			57.7 a[§]	58.9 a	1.2 b	229.6	136.1	4.31 a
LVN10			55.4 b	56.9 b	1.5 a	230.8	137.1	4.11 b
$LSD_{0.05}$			0.4**	0.3**	0.2**	NS	NS	0.1*
	57,000		56.7	57.6 b	0.9 c	227.8 c	132.6 b	3.64 c
	71,000		56.7	57.9 b	1.2 b	231.1 b	137.6 a	4.29 b
	84,000		56.2	58.2 a	2.0 a	233.4 a	138.7 a	4.70 a
$LSD_{0.05}$			NS	0.4*	0.3**	2.1**	1.7**	0.12**
		0	57.4 a	59.3 a	1.9 a	215.4 d	126.5 d	3.39 d
		60	56.9 b	58.3 b	1.4 b	230.1 c	135.8 c	3.94 c
		120	56.2 c	57.4 c	1.2 b	232.9 b	138.6 b	4.42 b
		180	56.1 c	57.3 c	1.2 b	236.1 a	141.0 a	4.60 a
		240	56.0 c	57.1 c	1.1 b	238.0 a	141.2 a	4.70 a
$LSD_{0.05}$			0.6**	0.5**	0.3**	2.6**	2.2**	0.15**
CV(a) %			1.9	1.4	42.9	3.1	3.8	20.7
CV(b) %			1.4	1.7	48.5	2.8	4.1	9.4
CV(c) %			1.5	1.3	35.3	1.7	2.4	17.2

[§] In a column, means with different letters are significantly different at $P < 0.05$.

*, ** = Significant at $P < 0.05$ and $P < 0.01$, respectively.

NS = Non-significant at $P < 0.05$.

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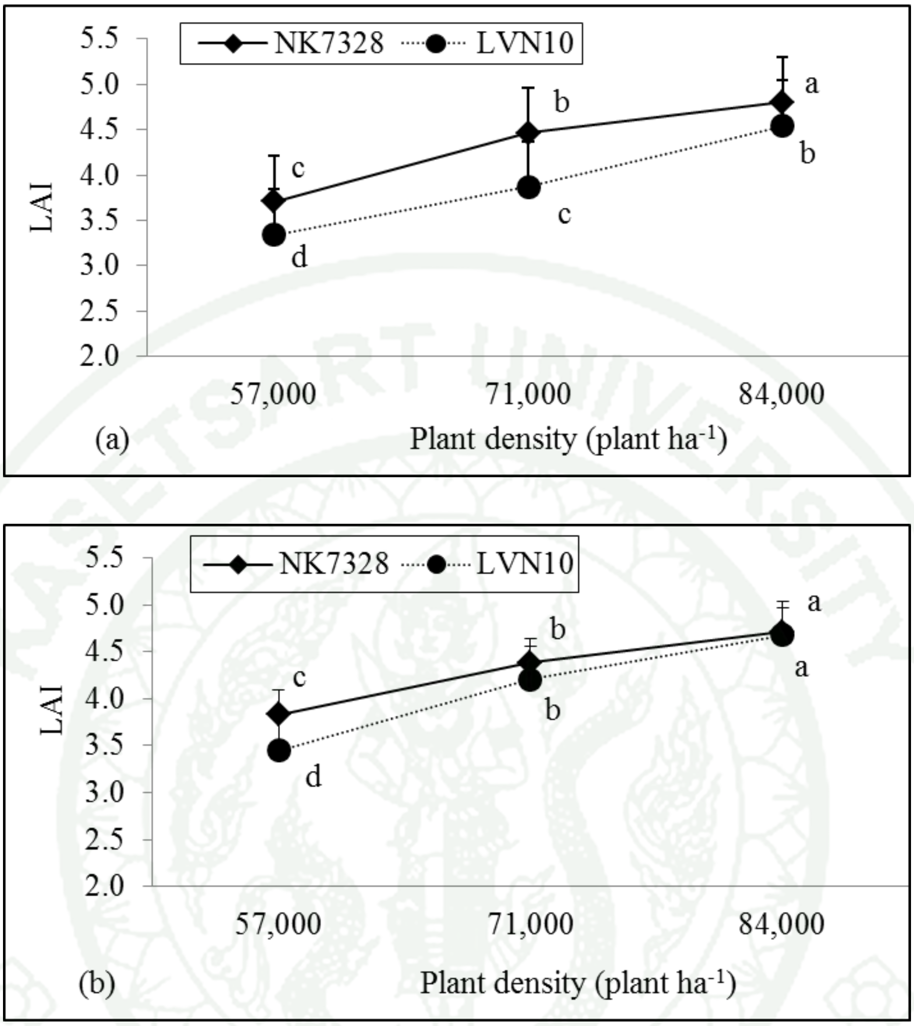

Figure 3 Interaction effects of hybrids and plant densities on leaf area index (LAI) at VT stage at Ba Ria (a) and Dong Nai (b). Means with different letters are significantly different at $P < 0.05$.

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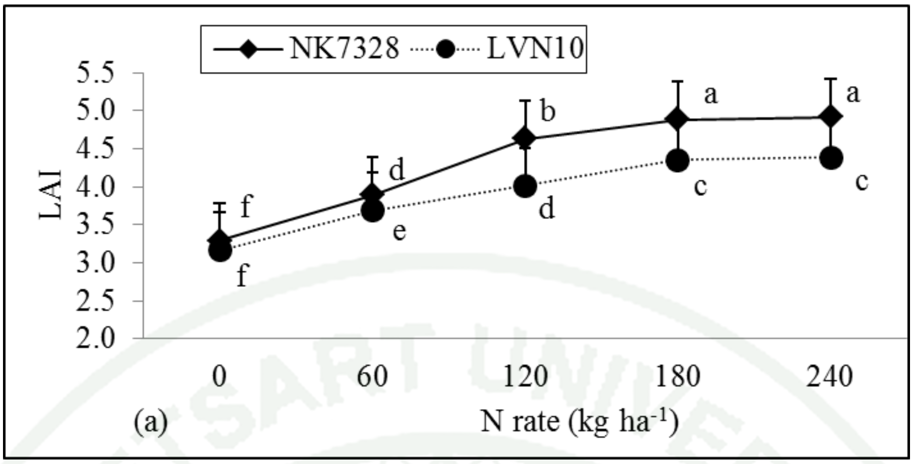

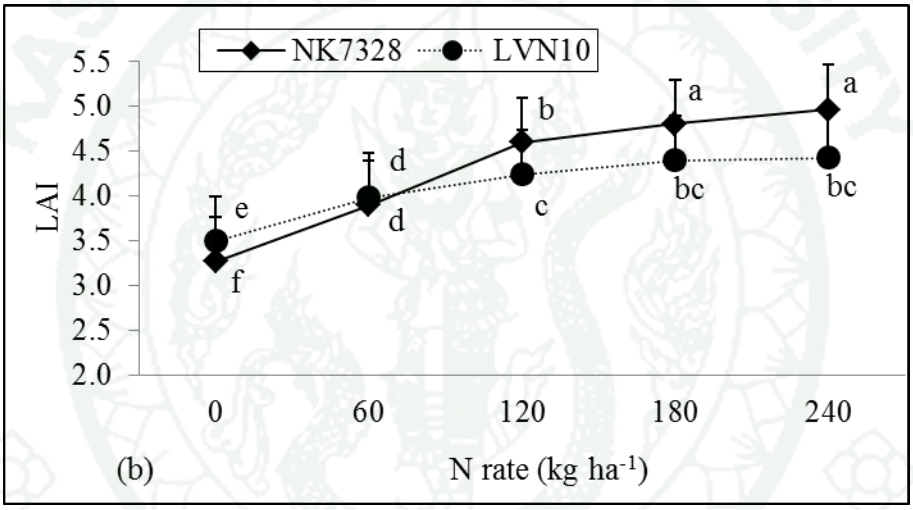

Figure 4 Interaction effects of hybrids and nitrogen fertilizer rates on leaf area index (LAI) at VT stage Ba Ria (a) and Dong Nai (b). Means with different letters are significantly different at $P < 0.05$.

Moreover, the values of LAI at tasseling stage were the lowest at 54,000 plants ha^{-1} and 0 kg N ha^{-1} treatment combination at Ba Ria and the same 54,000 plants ha^{-1} and 0 kg N ha^{-1} treatment combination at Dong Nai. These results conformed to the findings of Ciampitti and Vyn (2011) who showed that under medium N application at low and intermediate plant density treatments regardless of the hybrids and locations, overall LAI was greater at the highest density than that at the low and medium plant densities.

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2. Grain yield and yield components

2.1 Grain yield response to plant density

The trend for hybrid effects on grain yield at both locations was the same (Tables 4 and 5). The hybrid NK7328 yielded significantly greater grain yield than LVN10 about 13% and 20% at Ba Ria and Dong Nai, respectively. The main effects of hybrid were more important in determining yield than the interactions. Increased plant density was accompanied by the increase in grain yield. At Ba Ria (Table 4), plant density had a highly significant effect on grain yield unit area^{-1} ($P < 0.01$). Grain yield unit area^{-1} increased with increasing plant density from 54,000 to 71,000 plants ha^{-1} but decreased when plant density increased from 71,000 to 84,000 plants ha^{-1}. Grain yield of maize planted at 71,000 plants ha^{-1} was 8.11 tons ha^{-1} which was 12 and 5% greater than those planted at 54,000 and 84,000 plants ha^{-1}, respectively. Increase plant density usually caused plants and stems to become smaller, weaker and often taller (Gardner *et al.,* 1985). Some of the most concerns about increasing plant density are the increased risk associated with lodging and barren plant. 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 grain filling stage at Ba Ria and grain yield seemed to be affected by the root lodging at high plant density treatment (data not shown). This might cause reduction in grain yield at high plant density of this experiment.

At Dong Nai, grain yield unit area^{-1} was also significantly affected by plant density (Table 5). Grain yield unit area^{-1} increased linearly with increasing plant density from 54,000 to 84,000 plants ha^{-1}. Maize planted at the maximum plant density gave the greatest grain yield at 8.05 tons ha^{-1} which was 21% and 7% greater than grain yield of maize planted at 54,000 and 71,000 plants ha^{-1}, respectively.

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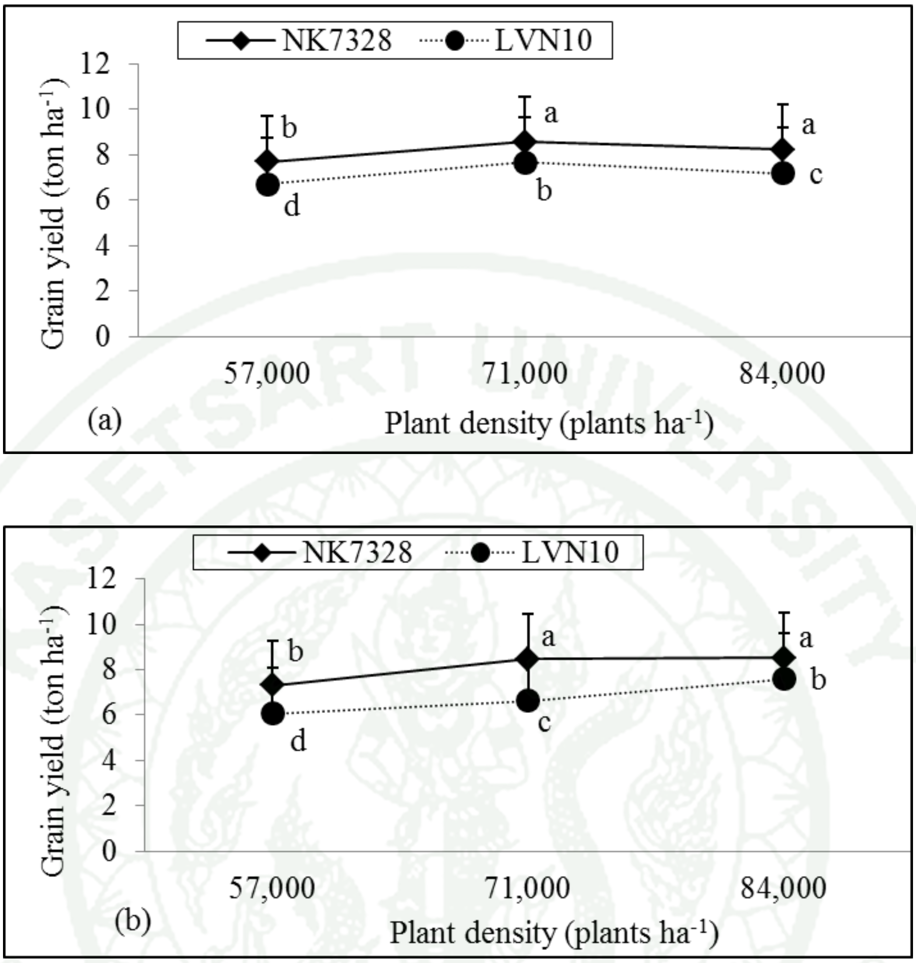

Figure 5 Effects of plant densities on grain yield of two maize hybrids at Ba Ria (a) and Dong Nai (b). Means with different letters are significantly different at $P < 0.05$.

Figures 5a and 5b indicated significant differences in grain yield of two maize hybrids due to increasing plant density. Both hybrids produced greater grain yield at higher plant density of 84,000 and 71,000 plants ha^{-1}. Although the grain yield observed either increased or reduced at both locations but there was no significant difference in grain yield of NK7328 hybrid between plant density of 71,000 and 84,000 plants ha^{-1} across two locations. Thus for NK7328 hybrid the maximum plant density produced the highest grain yield must be less than 84,000 plants ha^{-1}. On the contrary, for LVN10 hybrid the optimum plant density was 71,000 plants ha^{-1}. In general, the environmental factors such as climate, moisture and soil

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fertility also influence the optimum plant density. The limitation of these environmental factors lowers the optimum plant density for maximum production (Gardner *et al*., 1985).

2.2 Grain yield response to N fertilizer rate

At Ba Ria, N fertilizer rate had a significant effect on grain yield per unit area of maize hybrid (Table 4). Grain yield per unit area increased linearly with increasing N fertilizer rates from 0 kg N ha^{-1} up to 180 kg N ha^{-1}. The highest N fertilizer treatment produced the greatest grain yield (8.97 tons ha^{-1}) by an average of 73% higher than did the lowest N fertilizer rate. Grain yield was increased about 36 and 63% when N fertilizer rate increased from control (0 kg N ha^{-1}) to 60 kg N ha^{-1} and 120 kg N ha^{-1}, respectively. However, there was no significant difference in grain yield between 180 and 240 kg N ha^{-1} treatments.

At Dong Nai, there was also significant difference in grain yield as affected by N fertilizer application (Table 5). It was clearly showed that grain yield increased drastically from 5.06 tons ha^{-1} to 8.64 tons ha^{-1}, or an average of 71% higher when increasing N rate from control 0 kg to 240 kg N ha^{-1}. The greatest grain yield was obtained from corn applied with the highest N fertilizer rate (240 kg N ha^{-1}), however it was not different from corn receiving 180 kg N ha^{-1}. This result was supported by Alam *et al*. (2003) who reported that grain yield increased progressively with added N fertilizer up to 180 kg N ha^{-1}.

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Table 4 Effects of plant densities and nitrogen fertilizer rates on grain yield and yield components of two maize hybrids at Ba Ria during the wet season 2011 (Apr-Aug).

Hybrid	PD (plants ha^{-1})	N rate (kg ha^{-1})	Yield (ton ha^{-1})	Ear length (cm)	No. of row ear^{-1}	No. of kernel ear^{-1}	1,000-kernel Wt. (g)
NK7328			8.16 a[§]	16.7	13.2 a	442.9 a	315.7 a
LVN10			7.19 b	16.6	11.8 b	404.9 b	306.6 b
$LSD_{0.05}$			0.23**	NS	0.2**	6.6**	1.9**
	57,000		7.21 c	17.4 a	12.7 a	451.1 a	330.1 a
	71,000		8.11 a	16.6 b	12.6 a	422.9 b	301.8 b
	84,000		7.71 b	16.0 c	12.3 b	397.7 c	301.6 b
$LSD_{0.05}$			0.29**	0.2**	0.2*	8.1**	2.3**
		0	5.19 d	14.9 d	12.2 c	352.2 d	263.5 e
		60	7.07 c	16.1 c	12.3 bc	384.5 c	294.7 d
		120	8.38 b	17.2 b	12.7 a	453.7 b	319.5 c
		180	8.77 a	17.4 ab	12.6 ab	457.2 b	337.2 b
		240	8.97 a	17.6 a	12.8 a	471.7 a	340.9 a
$LSD_{0.05}$			0.37**	0.3**	0.3**	10.5**	3.0**
CV(a) %			5.0	4.1	3.7	10.3	3.0
CV(b) %			6.2	5.9	4.0	6.8	2.3
CV(c) %			7.2	2.6	3.3	3.7	1.4

[§] In a column, means with different letters are significantly different at $P < 0.05$.

*, ** = Significant at $P < 0.05$ and $P < 0.01$, respectively.

NS = Non-significant at $P < 0.05$.

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Table 5 Effects of plant densities and nitrogen fertilizer rates on grain yield and yield components of two maize hybrids at Dong Nai during the wet season 2011 (Apr-Aug).

Hybrid	PD (plant ha^{-1})	N rate (kg ha^{-1})	Yield (ton ha^{-1})	Ear length (cm)	No. of row ear^{-1}	No. of kernel ear^{-1}	1,000-kernel Wt. (g)
NK7328			8.09 a[§]	15.8	13.7 a	431.5 a	296.0 a
LVN10			6.76 b	16.0	12.2 b	404.8 b	267.1 b
$LSD_{0.05}$			0.25**	NS	0.2**	7.8**	2.0**
	57,000		6.68 c	16.2 a	13.5 a	427.8 a	283.7 a
	71,000		7.54 b	15.9 b	13.2 a	426.2 a	276.1 b
	84,000		8.05 a	15.6 c	12.8 b	400.3 b	270.0 c
$LSD_{0.05}$			0.31**	0.2**	0.3*	9.5**	2.5**
		0	5.06 d	14.5 e	12.3 c	322.9 e	243.5 e
		60	7.08 c	15.3 d	12.8 b	380.5 d	261.0 d
		120	8.04 b	16.2 c	13.0 a	435.3 c	280.7 c
		180	8.31 ab	16.7 b	13.3 a	471.5 b	296.1 b
		240	8.64 a	17.0 a	13.3 a	480.4 a	301.7 a
$LSD_{0.05}$			0.39**	0.2**	0.3**	12.3**	3.2**
CV(a) %			11.6	4.2	2.8	3.1	1.8
CV(b) %			11.6	2.6	4.2	6.5	2.4
CV(c) %			7.9	2.2	3.6	4.4	1.7

[§] In a column, means with different letters are significantly different at $P < 0.05$.

*, ** = Significant at $P < 0.05$ and $P < 0.01$, respectively.

NS = Non-significant at $P < 0.05$.

The grain yield response of each maize hybrid to N fertilizer rates was determined. At both locations, the least-squares linear regression analysis showed that grain yield of two hybrids increased linearly with an increase N rate (Figures 6 and 7).

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At Ba Ria, there was a significant relationship between grain yield and N fertilizer rate for maize hybrid NK7328 ($R^2 = 0.85$, $P < 0.05$) and LVN10 ($R^2 = 0.88$, $P < 0.05$) (Figures 6a and 6b).

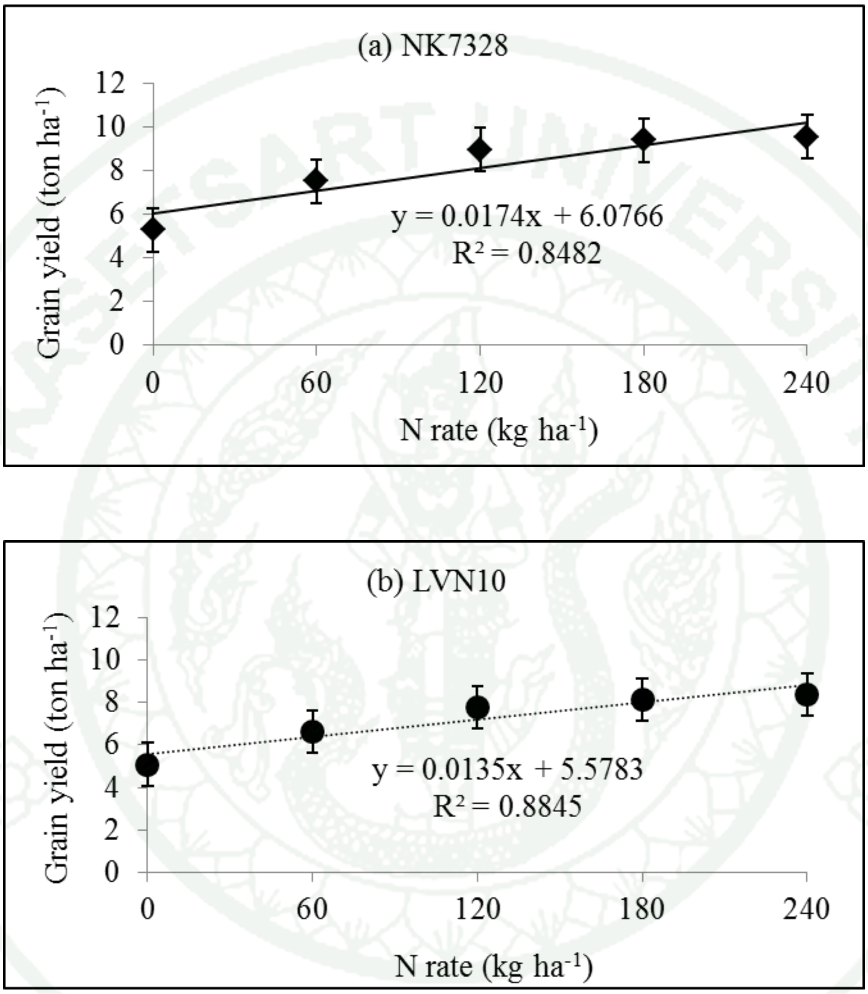

Figure 6 Relationship between nitrogen fertilizer rates and grain yield of two maize hybrids NK7328 (a), LVN10 (b) at Ba Ria.

At Dong Nai, only significant relationship between grain yield and N rate for maize hybrid NK7328 ($R^2 = 0.89$, $P < 0.05$) was observed but LVN10 (Figure 7). This might be due to LVN10 was an older hybrid, has less ability to acquire N nutrient such as N uptake, recycling efficiency from vegetative tissues to developing kernels resulted in lower grain yield. Other findings (Rajcan and Tollenaar, 1999) supported that the total N uptake in the above-ground portions of maize was 10 and

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18% greater in the new than in the old hybrid under low and high soil-N conditions, respectively.

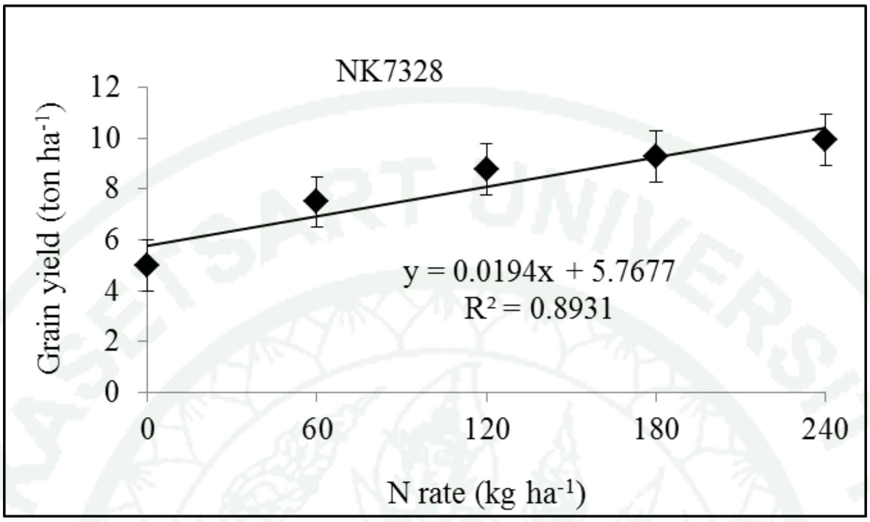

Figure 7 Relationship between nitrogen fertilizer rates and grain yield of maize hybrid K7328 at Dong Nai.

Figure 8 showed the interaction effect of plant density and N fertilizer rate on grain yield of two maize hybrids. There was significant effect in Ba Ria only (Figure 8). Overall, the grain yield of two hybrids increased with increasing both plant density and N fertilizer rate. However, grain yield was not different when N rate was increased from 180- 240 N kg ha^{-1} at three plant densities. Thus, it was concluded that plant density of 71,000 plants ha^{-1} and N rate at 120 to 180 kg N ha^{-1} will be the optimum for both hybrids to produce the highest grain yield.

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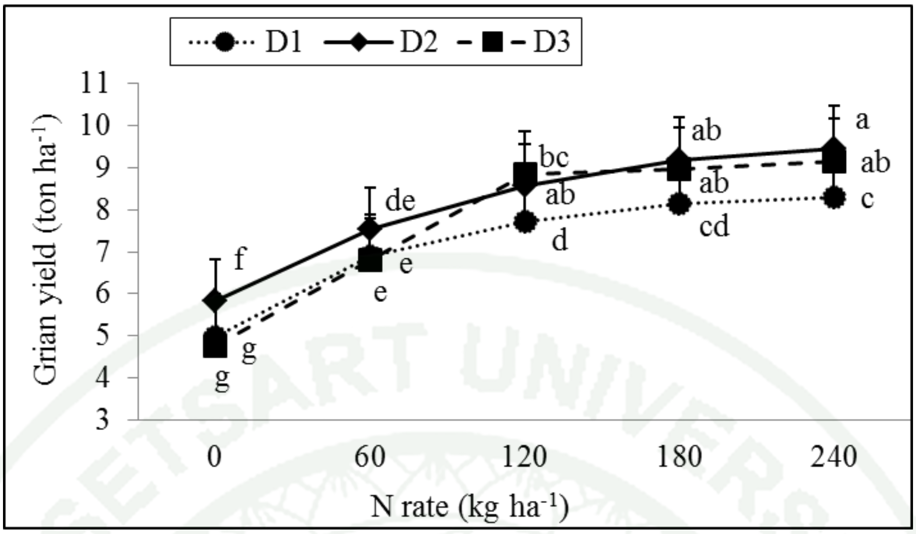

Figure 8 Interaction effects of plant densities and nitrogen rates on grain yield at Ba Ria: D1 = 57,000 plants ha^{-1}; D2 = 71,000 plants ha^{-1}; D3 = 84,000 plants ha^{-1}. Means with different letters are significantly different at $P < 0.05$.

2.3 Grain yield components

2.3.1 Ear length

Analysis of variance and the *F*-test of ear length showed significantly different as affected by plant density and N fertilizer rate but did not differ among two maize hybrids at both locations (Tables 4 and 5). At Ba Ria, plant density and N fertilizer rate were significant for ear length (Table 4). Ear length of maize reduced when plant density was increased. The lowest plant density of 57,000 plants ha^{-1} gave the longest ear length of 17.4 cm, while maize planted at 71,000 and 84,000 plants ha^{-1} produced shorter ear length of 16.6 cm and 16 cm, respectively. Higher N fertilizer rate resulted in increasing ear length. However, increasing N rate from 120 to 240 kg N ha^{-1} did not increase ear length. Ear length reduced with increasing plant density was also reported by Bavec and Bavec (2002) and Tokatlidis *et al.* (2005).

At Dong Nai, the effect of plant density and N fertilizer rate on ear length showed a consistent trend with that observed at Ba Ria (Table 5). There was a

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significant difference in ear length from different plant densities. The longest ear length was recorded at the lowest plant density of 57,000 plants ha^{-1}. Ear length increased when increasing N fertilizer rates. Likewise, the highest N fertilizer rate gave ear length of 17 cm, followed by N fertilizer rate of 180 kg N ha^{-1} with a 16.7 cm, while other three N treatments 120 kg N ha^{-1}, 60 kg N ha^{-1} and 0 kg N ha^{-1} produced the lower values of 16.2 cm, 15.3 cm and 14.5 cm, respectively.

2.3.2 Number of kernel row ear^{-1}

The results in table 4 and 5 showed that there was a significant difference in number of kernel row ear^{-1} as affected by maize hybrid, plant density and N fertilizer rate at both Dong Nai and Ba Ria. NK7328 hybrid produced greater number of kernel row ear^{-1} than LVN10. The number of kernel row ear^{-1} decreased with increasing plant density from 57,000 to 84,000 plants ha^{-1} but no significant difference between plant density of 57,000 and 71,000 plants ha^{-1}. Maize planted at the maximum plant density produced the lowest number of kernel row ear^{-1}. The number of kernel row ear^{-1} increased with increasing N fertilizer rate from 0 kg to 120 kg N ha^{-1}. The highest N fertilizer treatment produced the greatest number of kernel row ear^{-1} (12.8) and it was clearly that number of kernel row ear^{-1} was not affected when N rate was increased from 120 to 240 kg N ha^{-1}. There was no significant interaction effect among maize hybrid, plant density and N fertilizer rate on number of kernel row ear^{-1}. Overall, the results indicated that the number of kernel row ear^{-1} was influenced more by genetics.

2.3.3 Number of kernel ear^{-1}

There was a significant effect of hybrid, plant density and N fertilizer rate on numbers of kernel ear^{-1} at Dong Nai and Ba Ria (Tables 4 and 5). NK7328 hybrid produced greater numbers of kernel ear^{-1} than LVN10 hybrid at two locations, numbers of kernel ear^{-1} of hybrids ranged from 443 to 405 for these hybrids, respectively. Numbers of kernel ear^{-1} decreased linearly with increasing plant density from 57,000 to 84,000 plants ha^{-1}. Maize planted at the maximum plant density gave

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the lowest numbers of kernel ear^{-1} was 398 and 400 at Ba Ria and Dong Nai, respectively. However the reduction of number of kernel ear^{-1} was not enough to reduce grain yield. In addition, higher plant density produced higher number of ear area^{-1} this might compensate to the reduction of number kernel ear^{-1}. Consequently, higher plant density yielded greater grain yield unit area^{-1}. This result showed consistently with the report of Lemcoff and Loomis (1994) and Bavec and Bavec (2002). Higher N rates resulted in higher numbers of kernel ear^{-1}. The highest number of kernel ear^{-1} was observed at 240 kg N ha^{-1} and the lowest was recorded at 0 kg N ha^{-1}. There was also interaction effect of maize hybrid and plant density, maize hybrid and N fertilizer rate on numbers of kernel ear^{-1} (Tables 6 and 7). Two maize hybrids NK7328 and LVN10 gave the highest number of kernel ear^{-1} at the lowest plant density and the N fertilizer rate at 180 kg N ha^{-1} or 240 kg N ha^{-1}.

2.3.4 The 1,000-kernel weight

The results in table 4 and 5 illustrated that maize hybrid, plant density, and N fertilizer rate had a significant effect on kernel weight at two locations. NK7328 hybrid produced greater 1,000-kernel weight than LVN10, an average 9.1 gram and 28 gram at Ba Ria and Dong Nai, respectively. The kernel weight decreased as plant density increased. The highest 1000-kernel weight was seen at 57,000 plants ha^{-1}, while the plant densities at 71,000 and 84,000 plants ha^{-1} gave the lowest 1000-kernel weight. N fertilizer rate showed highly significant effect on kernel weight. Kernel weight increased linearly as increasing N fertilizer rate. The highest 1,000-kernel weight ranged 340.9 gram was recorded at 240 N kg ha^{-1} whereas the lowest kernel weight was seen at 0 N treatment was 243.5 gram. However, the increase in kernel weight was due to increase N rates from 180 to 240 N kg ha^{-1} showed lesser value compared to those increase from 0 kg to 180 kg ha^{-1}. This result was supported by Melchiori and Caviglia (2008) who reported that kernel weight increased with increasing N fertilizer application. There was a significant interaction effect of maize hybrid and N rate, maize hybrid and plant density on 1,000-kernel weight at both locations (Tables 6, 7 and 8). Two maize hybrids NK7328 and LVN10 produced the

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highest 1,000-kernel weight at the lowest plant density of 57,000 plants ha^{-1} and N rate of 180 to 240 kg N ha^{-1}.

Table 6 Interaction effects of nitrogen fertilizer rates and maize hybrids on grain yield and yield components at Ba Ria during the wet season 2011(Apr-Aug).

Hybrid	N rate (kg ha^{-1})	Yield (ton ha^{-1})	Ear length (cm)	No. of row ear^{-1}	No. of kernel ear^{-1}	1,000-kernel Wt. (g)
NK7328	0	5.30 g[§]	14.8 e	12.7	358.6 g	263.6 f
	60	7.53 e	16.3 c	12.8	399.6 e	307.5 e
	120	8.98 b	17.2 a	13.6	478.6 b	327.1 c
	180	9.43 ab	17.5 a	13.3	479.3 b	340.0 a
	240	9.57 a	17.6 a	13.6	498.3 a	340.4 a
LVN10	0	5.08 g	15.0 d	11.7	345.8 f	263.4 f
	60	6.61 f	15.9 c	11.8	369.3 g	281.9 g
	120	7.79 de	17.1 b	11.8	428.9 d	311.9 d
	180	8.11 cd	17.4 a	11.8	435.2 cd	334.5 b
	240	8.37 c	17.6 a	11.9	445.2 c	341.4 a
$LSD_{0.05}$		0.52**	0.4*	NS	14.8*	4.3**
CV (%)		7.2	3.3	2.6	3.7	1.4

[§] In a column, means with different letters are significantly different at $P < 0.05$.

*, ** = Significant at $P < 0.05$ and $P < 0.01$, respectively.

NS = Non-significant at $P < 0.05$.

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Table 7 Interaction effects of plant densities and maize hybrids on grain yield and yield components at Ba Ria and Dong Nai during the wet season 2011 (Apr-Aug).

Hybrid	PD (plant ha^{-1})	Yield (ton ha^{-1})	Ear length (cm)	No. of row ear^{-1}	No. of kernel ear^{-1}	1,000-kernel Wt.(g)
			Ba Ria			
NK7328	57,000	7.70 b[§]	17.2 a	13.3 a	461.5 a	329.6 b
	71,000	8.56 a	16.6 b	13.1 a	440.3 b	314.1 c
	84,000	8.23 a	16.2 c	13.2 a	426.8 c	303.5 d
LVN10	57,000	6.72 d	17.5 a	12.0 b	440.7 b	330.6 a
	71,000	7.66 b	16.5 bc	12.1 b	405.5 d	299.6 e
	84,000	7.19 c	15.8 d	11.4 c	368.5 e	289.7 f
$LSD_{0.05}$		0.4*	0.3*	0.3**	11.5**	3.3**
CV (%)		6.2	5.9	4.0	6.8	2.3
			Dong Nai			
NK7328	57,000	7.29 b	16.2	13.5	446.0	305.0 a
	71,000	8.47 a	15.8	13.9	436.0	295.8 b
	84,000	8.51 a	15.4	13.7	412.6	287.3 c
LVN10	57,000	6.07 d	16.3	12.1	409.2	262.4 d
	71,000	6.61 c	16.0	12.5	417.0	256.4 e
	84,000	7.60 b	15.9	12.0	388.1	252.7 e
$LSD_{0.05}$		0.43*	NS	NS	NS	3.5**
CV (%)		11.6	2.6	4.2	6.5	2.4

[§] In a column, means with different letters are significantly different at $P < 0.05$.

*, ** = Significant at $P < 0.05$ and $P < 0.01$, respectively.

NS = Non-significant at $P < 0.05$.

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Table 8 Interaction effects of nitrogen fertilizer rates and maize hybrids on grain yield and yield components at Dong Nai during the wet season 2011(Apr-Aug).

Hybrid	N rate (kg ha^{-1})	Yield (ton ha^{-1})	Ear length (cm)	No. of row ear^{-1}	No. of kernel ear^{-1}	1,000-kernel Wt. (g)
NK7328	0	5.00 e	14.1 f	12.8	323.3 f	253.5 e
	60	7.49 c	15.1 e	13.5	389.9 d	275.0 d
	120	8.77 b	16.2 c	13.9	454.3 b	304.8 c
	180	9.26 b	16.7 b	14.0	487.0 a	318.4 b
	240	9.92 a	16.9 ab	14.2	502.9 a	328.6 a
LVN10	0	5.12 e	14.8 e	11.7	322.4 f	233.7 g
	60	6.66 d	15.5 d	12.2	371.1 e	246.9 f
	120	7.30 c	16.1 c	12.1	416.4 c	256.6 e
	180	7.35 c	16.7 b	12.5	456.0 b	273.9 d
	240	7.35 c	17.1 a	12.4	457.9 b	274.9 d
$LSD_{0.05}$		0.6**	0.3*	NS	17.4*	4.5**
CV (%)		7.9	2.2	3.6	4.4	1.7

§ In a column, means with different letters are significantly different at $P < 0.05$.

*, ** = Significant at $P < 0.05$ and $P < 0.01$, respectively.

NS = Non-significant at $P < 0.05$.

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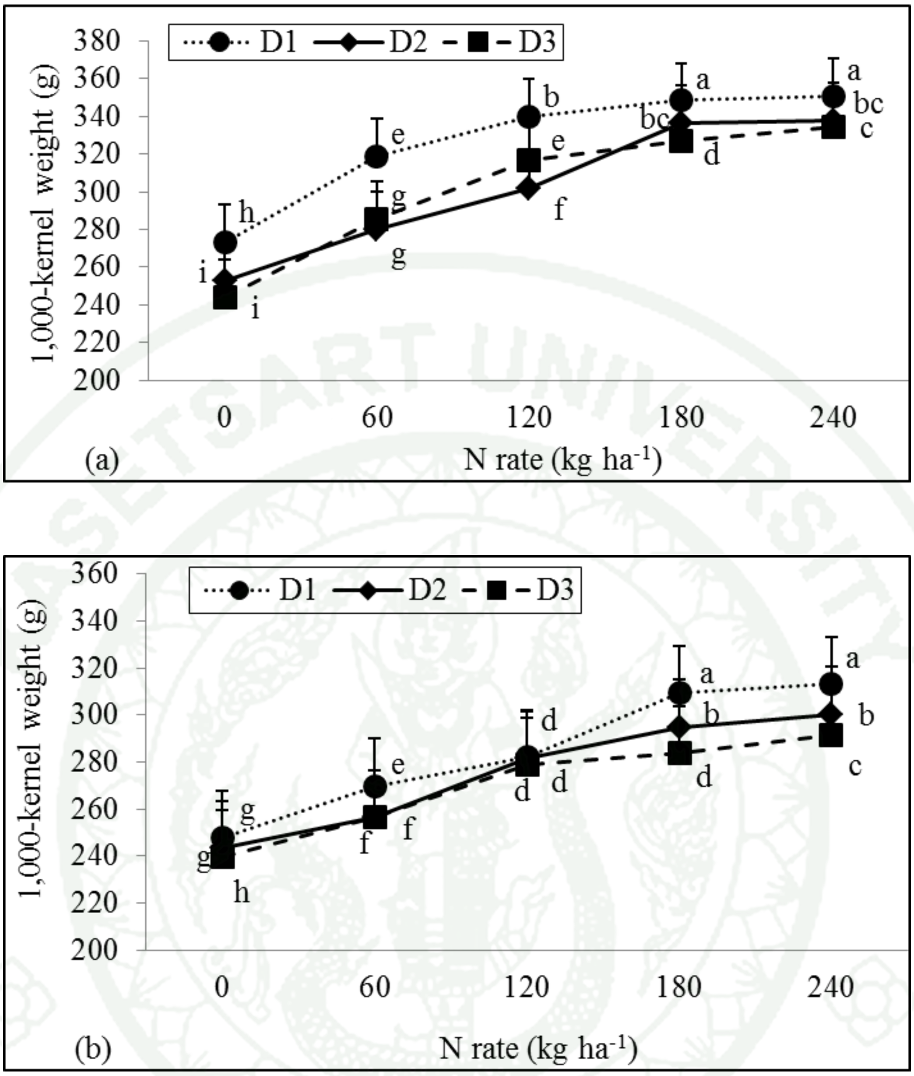

Figure 9 Interaction effects of plant densities and N fertilizer rates on 1,000-kernel weight at Ba Ria (a) and Dong Nai (b) during the wet season 2011. D1 = 57,000 plants ha^{-1}; D2 = 71,000 plants ha^{-1}; D3 = 84,000 plants ha^{-1}. Means with different letters are significantly different at $P < 0.05$.

There was also significant interaction effect of plant density and N fertilizer rate on kernel weight (Figures 9a and 9b). At Ba Ria, 1,000-kernel weight attained a maximum value of 350.5 gram at the lowest plant density and the highest N fertilizer rate. Meanwhile, the minimum value of 244 gram was recorded at the highest plant density and 0 kg N fertilizer rate. The same trend of 1,000-kernel weight

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was observed at Dong Nai. Overall, two plant densities of 57,000 and 71,000 plants ha^{-1} did not differ on kernel weight when increasing N rate from 180 to 240 kg N ha^{-1}. This result indicated that with N fertilizer rate of 180 kg N ha^{-1} was sufficient nutrient requirement for maize plant to produce maximum kernel size under low and medium plant densities.

2.3.5 Correlation between grain yield and yield components

Table 9 showed correlation coefficient (r) of grain yield and yield components at two locations over the average of three plant densities and five N fertilizer rates. At Ba Ria, grain yield was correlated with 1,000-kernel weight (r = 0.02*), but did not correlate with any other yield component. Meanwhile, at Dong Nai grain yield had significant correlation with number of kernel row ear^{-1}, and there was also no significant correlation among grain yield with other components. This somewhat variation would indicate a general lack of consistency in grain yield performance from location to location. Thus, maize hybrid, plant density, N fertilizer and environmental condition during the growing season appeared to affect overall grain yield of maize.

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Table 9 Correlation coefficients (r) of grain yield and yield components at Ba Ria and Dong Nai.

Variables	Grain yield (ton ha^{-1})	
	Ba Ria	Dong Nai
Ear length	0.27	0.32
Number of kernel row ear^{-1}	0.34	0.48*
Number of kernel ear^{-1}	0.004	0.006
1,000-kernel weight	0.02*	0.01

* = Significant at $P < 0.05$.

3. Nitrogen use efficiency

The result in table 10 showed the effect of maize hybrid, plant density and N fertilizer rate on nitrogen use efficiency (NUE). The NUE of the two hybrids was significantly different at both locations. NK7328 hybrid gave significantly higher value of NUE than LVN10 with an average of 6 kg grain kg^{-1} N and 12 kg grain kg^{-1} N at Dong Nai and Ba Ria, respectively. Plant density had no significant effect on NUE. This indicated that increasing plant density of the two maize hybrids generally failed to improve NUE. Whereas N fertilizer rate highly influenced the NUE, and NUE declined as N fertilizer increased. The treatment of 60 kg N ha^{-1} gave the highest NUE (33 kg grain kg^{-1} N) and (33.6 kg grain kg^{-1} N) at Ba Ria and Dong Nai, respectively while the lowest average value of NUE was 15.5 kg grain kg^{-1} N from 240 kg N ha^{-1} treatment. However, there was no significant difference in NUE between treatment 180 and 240 kg N ha^{-1}. In generally, maize grain NUE was high at low N fertilizer rate.

There was significant interaction effect of maize hybrid and plant density on NUE only at Dong Nai (Figure 10). The NUE of NK7328 hybrid did not differ

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among the three plant densities. On the contrary, LVN10 hybrid recorded maximum value of NUE at plant density of 71,000 plant ha^{-1}. These results indicated that maize hybrid, plant density, N fertilizer rates, and environments all influence NUE. Moreover the primary factor affecting NUE was the proportional grain yield response to N applied. Furthermore, the result from this research showed that the highest NUE was not associated with the highest maize grain yield. Thus, further research is needed in order to improve both NUE and grain yield for greater maize productivity.

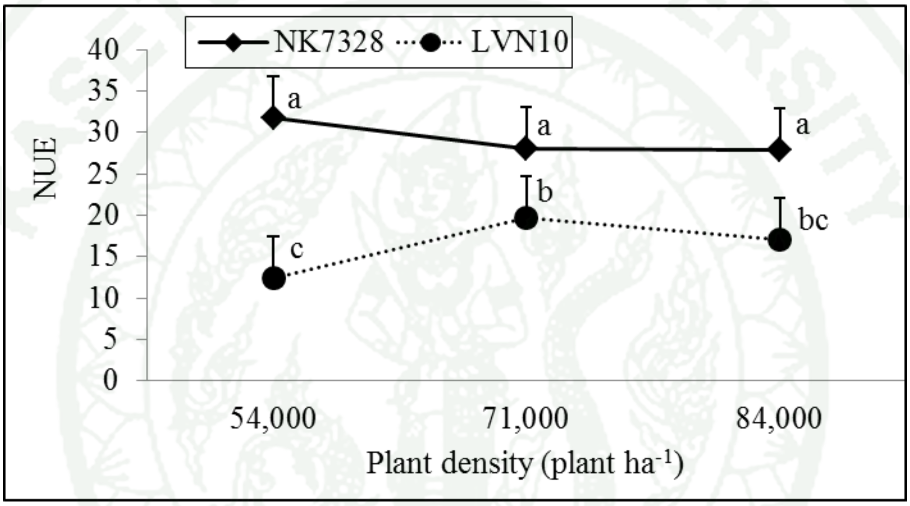

Figure 10 Interaction effects of maize hybrids and plant densities on nitrogen use efficiency at Dong Nai. Means with different letters are significantly different at $P < 0.05$.

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Table 10 Effects of plant densities and nitrogen fertilizer rates on nitrogen use efficiency (NUE) of two maize hybrids at Ba Ria and Dong Nai during the wet season 2011 (Apr-Aug).

Hybrid	PD (plants ha^{-1})	N rate (kg ha^{-1})	NUE at Ba Ria (kg kg^{-1})	NUE at Dong Nai (kg kg^{-1})
NK7328			27.0 a[§]	29.3 a
LVN10			21.4 b	16.4 b
$LSD_{0.05}$			3.8**	3.6**
	57,000		21.4	22.1
	71,000		24.1	23.9
	84,000		27.2	22.5
$LSD_{0.05}$			NS	NS
		0	-	-
		60	33.0 a	33.6 a
		120	27.3 b	24.8 b
		180	20.4 c	18.0 c
		240	16.1 c	14.9 c
$LSD_{0.05}$			5.4**	5.2**
CV(a) %			63.3	86.5
CV(b) %			56.7	51.8
CV(c) %			32.9	33.4

[§] In a column, means with different letters are significantly different at $P < 0.05$.

** = Significant at $P < 0.01$.

NS = Non-significant at $P < 0.05$.

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CONCLUSION

To investigate the response of maize hybrids to plant densities and nitrogen fertilizer rates under rainfed condition, two field experiments were conducted during the wet season 2011 at the major maize production area in the southern Vietnam. In general, the weather during the course of experiment was favorable to maize growth. The results can be concluded as follows:

The NK7328 maize hybrid performed better than LVN10 hybrid in terms of LAI, grain yield, and nitrogen use efficiency at two growing conditions. NK7328 had greater LAI at Ba Ria and Dong Nai than LVN10 (4.32 vs 3.92 and 4.31 vs 4.11, respectively). The NK7328 hybrid yielded significantly greater grain yield than LVN10 around 16% at both locations. Plant density had a significant effect on growth parameters of maize hybrids growing in the wet season. Increased plant density from 57,000 to 84,000 plants ha^{-1} resulted in increasing plant height, ear height, number of days to silking, ASI and LAI. Maize planted at the maximum plant density gave the greatest LAI about 4.7. LAI of maize planted at 71,000 and 84,000 plants ha^{-1} was greater, average around 18 to 33%, than those obtained from 54,000 plants ha^{-1}, respectively. Lower plant density always decreased LAI regardless of N fertilizer rates. Increased plant density from 54,000 to 84,000 plants ha^{-1} increased grain yield unit $area^{-1}$ but decreased yield components such as ear length, number of kernel row ear^{-1}, number of kernel ear^{-1} and 1,000-kernel weight. Grain yield of maize planted at 71,000 plants ha^{-1} was greater (12.5%) than those obtained from 54,000 plants ha^{-1}. The highest grain yield ranged 8.05-8.11 tons ha^{-1} which was attained by 71,000 and 84,000 plants ha^{-1} at Dong Nai and Ba Ria, respectively. Grain yield was significantly correlated with kernel weight and number of kernel row ear^{-1}.

Nitrogen fertilizer rate was strongly affected on growth of maize hybrid. Increased N rates resulted in the decrease in number of days to tasseling, number of days to silking and ASI. Higher N rates, up to 180 kg N ha^{-1} produced a taller plant height and ear height and greater LAI. Grain yield unit $area^{-1}$, ear length, number of

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kernel row ear^{-1}, number of kernel ear^{-1} and 1,000-kernel weight increased by increasing N fertilizer rates from 0 kg to 180 kg N ha^{-1}, the highest N fertilizer treatment (240 kg N ha^{-1}) produced the greatest grain yield by an average of 72% higher than did the control (0 kg N ha^{-1}). The existence of a linear relationship between N fertilizer rate and grain yield indicated the primary effect of N fertilizer to final grain yield of maize hybrid.

Nitrogen use efficiency of maize NK7328 and LVN10 hybrid were significantly affected by N fertilizer rates but plant density. NUE declined at an average of 17.5 kg grain kg^{-1} N when N rate increased from 60 to 180 kg N ha^{-1}. Furthermore, the highest NUE was not associated with the highest maize grain yield. For both new maize hybrid NK7328 and old hybrid LVN10, from these experiments, to achieve an optimum growth and yield the plant density was 71,000 plants ha^{-1} or 70 × 20 cm spacing and N fertilizer at rate of 120-180 kg N ha^{-1} be applied to maize under the rainfed condition in the southern Vietnam.

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LITERATURE CITED

Alam, M.M., M.M. Basher, A. Karim, M.A. Rahman and M.R. Islam. 2003. Effect of rate of nitrogen fertilizer and population density on the yield and yield attributes of maize. **Pak. J. Biol. Sci.** 6: 1770-1773.

Areerak, S., C. La-ied, P. Intanai, P. Grudloyma and A. Supannarat. 2008. Optimum nitrogen fertilizer rate of elite drought tolerant hybrid corn, pp. 514-517. *In* **Proc. 10th Asia Regional Maize Workshop,** Makassar, Indonesia.

Arif, M., I. Amin, M.T. Jan, I. Munir, K. Nawab, N.U. Khan and K.B. Marwat. 2010. Effect of plant population and nitrogen levels and methods of application on ear characters and yield of maize. **Pak. J. Bot.** 42: 1959-1967.

Bavec, F. and M. Bavec. 2002. Effects of plant population on leaf area index, cob characteristics and grain yield of early maturing maize cultivars. **European. J. Agron.** 16:151-159.

Begna, S. H. 1996. Effect of population density on the vegetative growth of leafy reduced-stature maize in a short-season area. **J. Agron. Crop Sci.** 12: 70-83.

Boomsma, C.R. and T.J. Vyn. 2007. Plant population influences on maize physiological responses to nitrogen application, pp. 136-144. *In* **Proc. 37th North Central Extension-Industry Soil Fertility Conference,** Des Moines, IA.

______., J.B. Santini, M. Tollenaar and T.J. Vyn. 2009. Maize morphophysiological response to intensive crowding and low nitrogen availability: An analysis and review. **Agron. J.** 101: 1426-1452.

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Bos, H.J., J. Vos and P.C. Struik. 2000. Morphological analysis of plant density effects on early leaf area growth in maize. **Netherlands. J. Agri. Sci.** 48: 199-212.

Cassman, K.G., A. Dobermann, D.T. Walters and H. Yang. 2003. Meeting cereal demand while protecting natural resources and improving environmental quality. **Annu. Rev. Environ. Resour.** 28: 315-358.

Ciampitti, I.A and T.J. Vyn. 2011. A comprehensive study of plant density consequences on nitrogen uptake dynamics of maize plants from vegetative to reproductive stages. **Field Crops Res.** 121: 2-18.

D'Andrea, K.E., M.E. Otegui and A.G. Cirilo. 2008. Kernel number determination differs among maize hybrids in response to nitrogen. **Field Crops Res.** 105: 228-239.

Dehdashti, S.M. and S. Riahinia. 2008. Effect of plant density on some growth indexes, radiation interception and grain yield in maize. **J. Biol. Sci.** 8: 908-913.

De Juan Valero, J.A., M. Maturano, A.A. Ramirez, J.M. Tarjuelo Martin-Benito and J. F. Ortega Alvarez. 2005. Growth and nitrogen use efficiency of irrigated maize in a semiarid region as affected by nitrogen fertilizer. **Spanish J. Agri. Res.** 3: 134-144.

Ding, L., K.J. Wang, G.M. Jiang, D.K. Biswas, H. Xu, L.F. Li and Y.H. Li. 2005. Effects of nitrogen deficiency on photosynthetic traits of maize hybrids released in different years. **Ann. Bot.** 96: 925-930.

Duncan, W.G. 1975. Maize, pp. 23-49. *In* L.T. Evans, ed. **Crop physiology: Some case histories.** Cambridge University Press, Cambridge.

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Duvick, D.N. 2005. Genetic progress in yield of United States maize (*Zea mays* L.). **Maydica** 50: 193-202.

Echarte, L., S. Luque, F.H. Andrade, V.O. Sadras, A. Cirilo, M.E. Otegui and C.R.C. Vega. 2000. Response of maize kernel number to plant density in Argentinean hybrids released between 1965 and 1993. **Field Crops Res.** 68: 1-8.

Gardner, F.P., R.B. Pearce and R.L. Mitchell. 1985. **Physiology of Crop Plants.** Iowa State University Press, Ames. USA.

Gehl, R.I., J.P. Schmidt, L.D. Maddux and W.B. Gordon. 2005. Corn yield response to nitrogen rate and timing in sandy irrigated soils. **Agron. J.** 97: 1230-1238.

General Statistical Office. 2010. **Statistical Yearbook of Vietnam.** Statistical Publishing House, Ha Noi, Vietnam.

Ha, D.T., T.D. Thao, N.T. Khiem, M.X. Trieu, R.V. Gerpacio and P. L. Pingali. 2004. **Maize in Vietnam: Production Systems, Constraints, and Research Priorities.** Mexico, D.F: CIMMYT.

Hao, P.X. and L.V. Hai. 2008. Effects of row spacing and densities on grain yields of five maize hybrids in three cropping seasons in Ha Tay province, pp. 494-498. *In* **Proc. 10th Asia Regional Maize Workshop,** Makassar, Indonesia.

Hokmalipour, S., R. Seyedsharifi, S.J. Somarin, M. Hassanzadeh, M.S. Janagard and R.Z. Mahmoodabad. 2010. Evaluation of plant density and nitrogen fertilizer on yield, yield components and growth of maize. **World Applied Sci. J.** 8: 1157-1162.

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Kien, T.T., P.X. Hao and D.T. Khiem. 2008. Effect of N, P, K Dosages on Grain Yield and Protein Quality of QPM Variety QP4 and Normal Maize Variety LVN 10 in Thai Nguyen, Vietnam, pp. 552-556. *In* **Proc. 10th Asia Regional Maize Workshop,** Makassar, Indonesia.

Lemcoff, J.H. and R.S. Loomis. 1994. Nitrogen and density influences on silk emergence, endosperm development, and grain yield in maize. **Field Crops Res.** 38: 63-72.

Ma, B.L., L.M. Dweyer and C. Costa. 2003. Row spacing and fertilizer nitrogen effects on plant growth and grain yield of maize. **Can. J. Plant Sci.** 83: 241-247.

Maddonni, G.A. and M.E. Otegui. 1996. Leaf area, light interception, and crop development in maize. **Field Crops Res.** 48: 81-87.

Malaviarachchi, M.A.P.W.K., K.M. Karunarathne and S.N. Jayawardane. 2007. Influence of plant density on yield of hybrid maize (*Zea mays* L.) under supplementary irrigation. **The J. Agri. Sci.** 3(2): 58-66.

Melchiori, R.J.M. and O.P. Caviglia. 2008. Maize kernel growth and kernel water relation as affected by nitrogen supply. **Field Crops Res.** 108: 198-205.

Moll, R.H., E.J. Kamprath and W.A. Jackson. 1982. Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. **Agron. J.** 74: 562-564.

Montgomery, E.G. 1911. Correlation studies in corn. **Neb. Agric. Exp. Stn. Annu. Rep.** 24: 108-159.

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Muchow, R.C. 1988. Effect of nitrogen supply on the comparative productivity of maize and sorghum in a semi-arid tropical environment. III. Grain yield and Nitrogen accumulation. **Field Crops Res.** 18: 31-43.

______. 1994. Effect of nitrogen on yield determination in irrigated maize in tropical and subtropical environments. **Field Crops Res.** 38: 1-13.

Nova, R. and R.S. Loomis. 1981. Nitrogen and plant production. **Plant and Soil** 58: 177-204.

Ogunlela, V.B., G.M. Amoruwa and O.O. Ologunde. 1988. Growth, yield components and micronutrient nutrition of field-grown maize as affected by nitrogen fertilizer and plant density. **Fertilizer Res.** 17: 189-196.

Paponov, I.A., P. Sambo, G.S. Erley, T. Presterl, H.H. Geiger and C. Engels. 2005. Grain yield and kernel weight of two maize genotypes differing in nitrogen use efficiency at various levels of nitrogen and carbohydrate availability during flowering and grain filling. **Plant and Soil** 272: 111-123.

Pokharel, B.B., S.K. Sah, L.P. Amgain and B.R. Ojha. 2008. Response of promising maize cultivars to different nitrogen levels during winter, pp. 560-564. *In* **Proc. 10th Asia Regional Maize Workshop,** Makassar, Indonesia.

Quy, K.L., M.X. Trieu and P.X. Hao. 2008. Current status of maize development in Vietnam and strategies to meet demand by 2020, pp. 21-24. *In* **Proc. 10th Asia Regional Maize Workshop,** Makassar, Indonesia.

Rahmati, H. 2009. Effect of plant density and nitrogen rate on yield and nitrogen efficiency of grain corn. **World Applied Sci. J.** 7: 958-961.

Rajcan, I. and C.J. Swanton. 2001. Understanding maize-weed competition: resource competition, light quality and the whole plant. **Field Crops Res.** 71: 139-150.

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______. and M. Tollenaar. 1999. Source - sink ratio and leaf senescence in maize: II. Nitrogen metabolism during grain filling. **Field Crops Res.** 60: 255-265.

Ritchie, S.W., J.J. Hanway and H.E. Thompson. 1996. How a corn plant develops. **Spec. Rep. 48. Coop. Ext. Serv.**, Iowa State Univ. of Sci. and Technol., Ames. IA.

Sangoi, L. and R.J. Salvador. 1998. Influence of plant height and of leaf number on maize production at high plant densities. **Pesquisa Agropecuaria Brasileira** 33: 377-388.

______., M. Ender, A.F. Guidolin, M.L. de Almeida and V.A. Konflanz. 2001. Nitrogen fertilizer impact on agronomic traits of maize hybrids released at different decades. **Pesquisa Agropecuaria Brasileira** 36(5): 757-764.

______., M.A. Gracietti, C. Rampazzo and P. Bianchetti. 2002. Response of Brazilian maize hybrids from different eras to changes in plant density. **Field Crops Res.** 79: 39-51.

Sani, B.M., K.O. Oluwasemire and H.I. Mohammed. 2008. Effect of irrigation and plant density on the growth, yield and water use efficiency of early maize in the Nigerian savanna. **ARPN J. Agri. Biol. Sci.** 3(2): 33-40.

Setiyono, T.D., D.T. Walters, K.G. Cassman, C. Witt and A. Dobermann. 2010. Estimating maize nutrient uptake requirements. **Field Crops Res.** 118: 158-168.

Subedi, K.D., B.L. Ma and D.L. Smith. 2006. Response of a leafy and non-leafy maize hybrid to population densities and fertilizer nitrogen levels. **Crop Sci.** 46: 1860-1869.

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Tokatlidis, I.S., V. Has, I. Mylonas, I. Has, G. Evgenidis, V. Melidis, A. Copandean and E. Ninou. 2010. Density effects on environmental variance and expected response to selection in maize (*Zea mays* L.). **Euphytica** 174: 283-291.

Tokatlidis, L.S., M.K. Sotiriou and E. Tamoutsidis. 2005. Benefits from using maize density-independent hybrid. **Maydica** 50: 9-17.

Tollenaar, M. 1989. Genetic improvement in grain yield of commercial maize hybrids grown in Ontario from 1959 to 1988. **Crop Sci.** 29: 1365-1371.

______., L.M. Dwyer and D.W. Stewart. 1992. Ear and kernel formation in maize hybrids representing three decades of yield improvement in Ontario. **Crop Sci.** 32: 432-438.

______., A. Aguilera and S.P. Nissank. 1997. Grain yield is reduced more by weed interference in an old than new maize hybrid. **Agron. J.** 89: 239-246.

Vos, J., P.E.L. Van der Putten and C.J. Brirch. 2005. Effect of nitrogen supply on leaf appearance, leaf growth, leaf nitrogen economy and photosynthetic capacity in maize. **Field Crops Res.** 93: 64-73.

Watson, D.J. 1947. Comparative physiological studies on the growth of field crops: I. variation in net assimilation rate and leaf area between species and varieties, and within and between years. **Ann. Bot.** 11(1): 46-76.

Westgate, M.E., F. Forcella, D.C. Reicosky and J. Somsen. 1997. Rapid canopy closure for maize production in the northern US Corn Belt: Radiation-use efficiency and grain yield. **Field Crops Res.** 49: 249-258.

Witt, C., J.M. Pasuquin and A. Dobermann. 2006. Towards a site-specific nutrient management approach for maize in Asia. **Better Crops** 90(2): 28-31.

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Yukui, R., P. Yunfeng, W. Zhengrui and Sh. Jianbo. 2009. Stem perimeter, height and biomass of maize (*Zea mays* L.) grown under different N fertilizer regimes in Beijing, China. **Int. J. Plant Production.** 3: 85-90.

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APPENDIX

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Appendix Table 1 Economic efficiency for corn production at Ba Ria (USD ha^{-1}).

PD	N rate	Seed	Urea	Labor and P + K	Total cost	Yield (t/ha)	Income	Profit	Profit / Cost
57,000	0	59.1	0	471.2	530.2	4.99	1460.6	930.3	1.75
	60	59.1	63.4	484.1	606.6	6.89	2016.7	1410.1	2.32
	120	59.1	126.8	489.9	675.8	7.73	2262.6	1586.8	2.35
	180	59.1	190.2	492.7	742.1	8.15	2385.5	1643.4	2.21
	240	59.1	254.6	493.7	807.4	8.29	2426.5	1619.1	2.01
71,000	0	73.6	0	491.5	565.1	5.82	1703.5	1138.5	2.01
	60	73.6	63.4	503.1	640.1	7.53	2204.0	1563.9	2.44
	120	73.6	126.8	510.2	710.6	8.56	2505.5	1794.9	2.53
	180	73.6	190.2	514.5	778.3	9.19	2689.9	1911.6	2.46
	240	73.6	254.6	516.3	844.5	9.46	2768.9	1924.4	2.28
83,000	0	87.1	0	499.0	586.1	4.78	1399.1	813.0	1.39
	60	87.1	63.4	512.8	663.3	6.80	1990.4	1327.1	2.00
	120	87.1	126.8	526.9	740.8	8.86	2593.3	1852.6	2.50
	180	87.1	190.2	527.6	804.9	8.97	2625.5	1820.6	2.26
	240	87.1	254.6	528.9	870.6	9.16	2681.1	1810.5	2.08

Other = Potassium (90 kg K ha^{-1}); phosphorus (90 kg P ha^{-1}); insecticides; herbicides.

Grain price = 292.7 USD ton^{-1}; Seed price = 4.15 USD kg^{-1}.

Urea price = 0.49 USD kg^{-1}; K price = 0.59 USD kg^{-1}; P price = 0.15 USD kg^{-1}.

Daily wage = 4.88 USD.

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Appendix Table 2 Balanced ANOVA for days to tasseling, days to silking and anthesis-silking interval (ASI) as affected by hybrid, plant density and N fertilizer rate at Ba Ria.

Source of variation	DF	Days to tasselling		Days to silking		ASI	
		MS	Prob.	MS	Prob.	MS	Prob.
Replication	2	0.6333	0.277	0.8444	0.144	0.2111	0.511
Hybrid (H)	1	124.844	0.000	54.4444	0.000	12.1000	0.000
Error (a)	2	0.1445	0.746	0.4444	0.900	0.3333	0.897
Plant density (PD)	2	2.4333	0.010	30.8778	0.000	16.4111	0.000
H × PD	2	3.6111	0.002	1.9444	0.015	0.4333	0.251
Error (b)	8	0.3389	0.687	0.3278	0.626	0.2722	0.532
Nitrogen (N)	4	12.2667	0.000	26.1389	0.000	2.9722	0.000
H × N	4	0.5111	0.385	1.7500	0.066	0.5722	0.129
PD × N	8	1.3500	0.062	0.3639	0.556	1.2306	0.001
H × PD × N	8	0.5278	0.381	0.4583	0.389	0.3639	0.324
Error (c)	48	0.4806	0.500	0.4222	0.500	0.3056	0.500
Total	89	2.5887		2.9538		1.0119	

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Appendix Table 3 Balanced ANOVA for plant height, ear height and leaf area index (LAI) as affected by hybrid, plant density and N fertilizer rate at Ba Ria.

Source of variation	DF	Plant height		Ear height		LAI	
		MS	Prob.	MS	Prob.	MS	Prob.
Replication	2	10.9000	0.448	37.7444	0.010	0.4287	0.362
Hybrid (H)	1	42.7111	0.075	38.6778	0.066	3.6767	0.000
Error (a)	2	4.0778	0.740	14.1445	0.161	0.7110	0.000
Plant density (PD)	2	430.300	0.000	582.711	0.000	9.9146	0.000
H × PD	2	127.544	0.060	69.9111	0.071	0.2133	0.009
Error (b)	8	10.2556	0.626	11.1611	0.186	0.1811	0.001
Nitrogen (N)	4	1281.82	0.000	1054.96	0.000	6.6862	0.000
H × N	4	1.8222	0.964	2.2611	0.876	0.2180	0.001
PD × N	8	62.7306	0.000	23.5861	0.006	0.6760	0.137
H × PD × N	8	14.9472	0.360	12.1194	0.145	0.5485	0.251
Error (c)	48	13.2083	0.500	7.5056	0.500	0.4118	0.500
Total	89	86.0719		72.0426		0.6456	

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Appendix Table 4 Balanced ANOVA for grain yield, ear length and kernel row ear^{-1} as affected by hybrid, plant density and N fertilizer rate at Ba Ria.

Source of variation	DF	Grain yield		Ear length		Kernel row ear^{-1}	
		MS.	Prob.	MS	Prob.	MS	Prob.
Replication	2	0.4337	0.249	0.20124	0.359	0.2564	0.223
Hybrid (H)	1	21.1245	0.000	0.21825	0.292	45.227	0.000
Error (a)	2	0.1479	0.952	0.46050	0.099	0.2084	0.295
Plant density (PD)	2	6.1239	0.000	14.5082	0.000	0.9884	0.005
H × PD	2	3.3431	0.039	1.14930	0.005	1.4631	0.001
Error (b)	8	0.2275	0.649	0.95782	0.851	0.2558	0.169
Nitrogen (N)	4	44.5339	0.000	23.3279	0.000	1.0185	0.001
H × N	4	0.8873	0.030	0.17491	0.466	0.6749	0.007
PD × N	8	0.6809	0.040	0.63258	0.004	0.3468	0.056
H × PD × N	8	0.2119	0.693	0.20920	0.386	0.2226	0.248
Error (c)	48	0.3036	0.500	0.19168	0.500	0.1663	0.500
Total	89	2.6916		1.6131		0.8137	

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Appendix Table 5 Balanced ANOVA for number kernel ear^{-1}, 1,000-kernel weight and nitrogen use efficiency (NUE) as affected by hybrid, plant density and N fertilizer rate at Ba Ria.

Source of variation	DF	Number kernel ear^{-1}		1,000-kernel weight		NUE	
		MS.	Prob.	MS	Prob.	MS	Prob.
Replication	2	254.740	0.361	120.493	0.005	210.711	0.046
Hybrid (H)	1	32437.2	0.000	1855.97	0.000	550.416	0.006
Error (a)	2	1895.27	0.001	89.2497	0.017	234.539	0.034
Plant density (PD)	2	21426.0	0.000	8068.36	0.000	200.865	0.053
H × PD	2	2688.56	0.000	1389.84	0.000	20.0120	0.735
Error (b)	8	829.532	0.004	50.8429	0.023	188.009	0.012
Nitrogen (N)	4	49460.1	0.000	18825.3	0.000	1002.80	0.000
H × N	4	1232.72	0.002	563.850	0.000	18.7673	0.829
PD × N	8	489.215	0.065	491.404	0.000	29.0728	0.835
H × PD × N	8	412.628	0.124	190.704	0.000	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	

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Appendix Table 6 Balanced ANOVA for days to tasseling, days to silking and anthesis-silking interval (ASI) as affected by hybrid, plant density and N fertilizer rate at Dong Nai.

Source of variation	DF	Days to tasselling		Days to silking		ASI	
		MS	Prob.	MS	Prob.	MS	Prob.
Replication	2	1.7334	0.111	3.0333	0.006	1.3000	0.007
Hybrid (H)	1	120.178	0.000	92.0111	0.000	1.8778	0.007
Error (a)	2	1.1111	0.241	0.6778	0.290	0.3444	0.238
Plant density (PD)	2	2.0333	0.078	3.0333	0.006	9.4333	0.000
H × PD	2	0.8778	0.325	0.4778	0.418	1.4778	0.004
Error (b)	8	0.6389	0.574	0.9556	0.102	0.4389	0.085
Nitrogen (N)	4	6.8222	0.000	15.5111	0.000	1.8222	0.000
H × N	4	0.5111	0.618	0.7333	0.256	0.5444	0.068
PD × N	8	0.4222	0.810	0.5611	0.412	0.1972	0.569
H × PD × N	8	1.5444	0.062	1.1167	0.055	0.7694	0.005
Error (c)	48	0.7611	0.500	0.5333	0.500	0.2333	0.500
Total	89	2.4540		2.4506		0.6618	

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Appendix Table 7 Balanced ANOVA for plant height, ear height and leaf area index (LAI) as affected by hybrid, plant density and N fertilizer rate at Dong Nai.

Source of variation	DF	Plant height		Ear height		LAI	
		MS.	Prob.	MS	Prob.	MS	Prob.
Replication	2	45.0528	0.064	29.5361	0.066	0.7660	0.240
Hybrid (H)	1	116.736	0.069	23.0028	0.139	0.8814	0.000
Error (a)	2	50.5861	0.047	27.1194	0.082	0.7594	0.866
Plant density (PD)	2	216.336	0.000	225.269	0.000	8.5143	0.000
H × PD	2	2.20278	0.869	98.1861	0.713	0.2274	0.018
Error (b)	8	41.8569	0.016	31.5944	0.088	0.1557	0.009
Nitrogen (N)	4	1505.99	0.000	662.323	0.000	5.3508	0.000
H × N	4	67.0208	0.005	27.1347	0.046	0.5042	0.000
PD × N	8	4.05139	0.975	4.39445	0.902	0.7008	0.247
H × PD × N	8	14.2792	0.514	21.1722	0.061	0.7020	0.246
Error (c)	48	15.6292	0.500	10.3840	0.500	0.5231	0.500
Total	89	92.9084		50.5256		0.5262	

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Appendix Table 8 Balanced ANOVA for grain yield, ear length and kernel row ear^{-1} as affected by hybrid, plant density and N fertilizer rate at Dong Nai.

Source of variation	DF	Grain yield		Ear length		Kernel row ear^{-1}	
		MS.	Prob.	MS	Prob.	MS	Prob.
Replication	2	2.3236	0.003	2.0639	0.000	0.1480	0.524
Hybrid (H)	1	39.9054	0.000	1.1138	0.064	50.775	0.000
Error (a)	2	0.7411	0.810	0.4518	0.698	0.1338	0.558
Plant density (PD)	2	14.4491	0.000	2.6841	0.000	1.3013	0.005
H × PD	2	1.7284	0.011	0.2553	0.133	0.3058	0.263
Error (b)	8	0.7474	0.047	0.1730	0.214	0.2889	0.268
Nitrogen (N)	4	37.4994	0.000	19.6580	0.003	0.1082	0.000
H × N	4	4.7774	0.000	0.4311	0.013	0.4540	0.103
PD × N	8	0.3977	0.348	0.4306	0.940	0.3369	0.178
H × PD × N	8	0.3945	0.353	0.1458	0.324	0.3547	0.152
Error (c)	48	0.3454	0.500	0.1224	0.500	0.2229	0.500
Total	89	3.0905		1.1274		0.9814	

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Appendix Table 9 Balanced ANOVA for number kernel ear^{-1}, 1,000-kernel weight and nitrogen use efficiency (NUE) as affected by hybrid, plant density and N fertilizer rate at Dong Nai.

Source of variation	DF	Number kernel ear^{-1}		1,000-kernel weight		NUE	
		MS	Prob.	MS	Prob.	MS	Prob.
Replication	2	2900.15	0.000	177.502	0.041	42.8049	0.491
Hybrid (H)	1	16052.3	0.000	33979.0	0.000	3000.52	0.000
Error (a)	2	167.200	0.617	25.5548	0.336	389.951	0.003
Plant density (PD)	2	7141.95	0.000	1404.72	0.000	20.5162	0.710
H × PD	2	679.439	0.142	123.645	0.008	200.060	0.042
Error (b)	8	741.840	0.043	43.3108	0.082	140.134	0.034
Nitrogen (N)	4	78799.4	0.000	10654.2	0.000	1237.29	0.000
H × N	4	1358.40	0.007	915.576	0.000	21.8496	0.774
PD × N	8	330.304	0.463	193.166	0.000	68.0984	0.344
H × PD × N	8	662.548	0.071	107.608	0.000	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	

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Appendix Figure 1 Plant and ear aspect of two maize hybris at harvesting time in Dong Nai.

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Appendix Figure 1 (Continued)

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