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Light interception and yield of some maize varieties grown in a double-row pattern under different urea applications

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Abstract. To increase light interception in maize by improving the population density using a double-row pattern planting often causes difficulty in applying fertilizers. This study aimed to assess the light interception and yield of some maize hybrid varieties treated with and without a third application of urea fertilizer. The varieties tested were NK7328, BISI18, BISI2, and P35. The first application of urea was performed at planting, the second at 35 days after planting (DAP), and the third at 56 DAP. The experiment was conducted in an arid area with a sandy loam soil in the North Lombok region. Spacing for the double-row pattern was 35 × 20 cm^2 within a double row and 70 cm between double rows, resulting in approximately 98,000 plants/ha. The results showed that light interception was significantly affected by the variety of maize but not by the third-time application of urea, being the highest (96.7%) in NK7328 and the lowest (92.0%) in BISI18. The yield was significantly affected by both the variety and the third application of urea. The highest yielding variety was P35 (9.7 ton/ha), followed by NK 7328 (9.5 ton/ha), BISI18 (8.8 ton/ha), and BISI2 (8.2 ton/ha). The third-time application of urea in a high maize population density improved the yield by 21%.

1. Introduction

A recent increase in air temperature resulting from climate change affects the production of food crops, including maize. Maize that grows well at an optimum temperature range of 30°C and 36°C can experience heat stress that affects its productivity by a delay in silking if the temperature exceeds the optimum [1]. The other effects of climate change, such as erratic rainfalls, also affect crop growth and yield. In arid and dryland areas, dry spells that occur during a rainy season reduce maize yield severely, especially when the dry spell happens during silking or the grain-filling stage [2]. However, climate change that triggers an increase in CO_2 concentration in the atmosphere can benefit maize crop as long as the other factors, such as water, nutrition, and temperature, are not limited. CO_2 is one of the growth factors that play an important role in the photosynthesis process, together with water and sunlight. An abundant amount of CO_2 and sunlight should be managed to increase the production of a crop, especially maize.

Maize is one of the agricultural products that have a high potential to increase country foreign exchange. Demand on maize keeps rising, and Indonesia, as one of the maize-producing countries in the world, has started exporting maize since 2018. To continue to improve the country's foreign exchange and the welfare of farmers through maize production, in addition to expanding the planting area, the technology of maize cultivation, especially the one that is adaptive to climate change, also needs to be continuously updated. The existence of modern hybrid varieties of maize with very high yield potentials must be used to the maximum extent by correct planting technology. As previously reported, modern hybrid varieties of maize have upright leaves due to their narrow leaf angle [3], and hence can be planted in a high population density. A high population of maize plants can increase yield per unit of the land area and also optimize the use of sunlight and CO_2, which are abundant. The population of maize plants is said to be optimum for maximum productivity if the plant canopy during the grain-filling phase can capture 95% of sunlight [4].

The population of maize plants is increased by a double- or twin-row pattern of planting [5]. In a double row, the spacing used is 35 cm between rows and 20 cm in a row, while the distance between double rows is 70 cm, yielding 98,000–100,000 plants/ha. Meanwhile, in conventional planting patterns, such as a single row, the spacing used is 70 cm between rows and 20 cm in a row, producing around 64,000–70,000 plants/ha. In terms of the role of maize leaves in capturing sunlight and absorbing CO_2 from the atmosphere, the double-row planting pattern is adaptive to the current climate change conditions because the plants can convert more CO_2 and sunlight into biomass and crop yields. However, which modern hybrid varieties of maize available in Indonesian markets have the best performance in double-row planting patterns is still not known.

The yield of maize is determined by the ability of plants to convert CO_2 and sunlight into carbohydrates (in the presence of sufficient water) and also the availability of nutrients. One of the important nutrients for maize plants is nitrogen, sourced from urea. Nitrogen has been reported to improve yields for maize crops, especially in a high crop population [6]. Sufficient nitrogen in the leaves during the grain-filling stage plays an important role in determining the maize yield [7]. In practice, most maize farmers are reluctant to apply urea for the third time to provide sufficient nitrogen during grain filling, especially in a high maize population density. The reason is mainly the technical difficulties encountered while going through the thick maize canopy. This study aimed to examine light interception and yield performance of some modern hybrid varieties of maize (production of PT BISI, Du Pont, and Syngenta), which were planted in a double-row pattern and treated with and without the third application of urea in an arid area with sandy loam soil.

2. Materials and method

A field trial was carried out in an arid area of Gumantar village, Kayangan subdistrict, North Lombok (8,253654 S, 116,285695 E), Indonesia, from May to October 2018. Soil properties at the experimental site were as follows: pH 6.6, C-organic 0.6%, N-total (Kjeldhal) 0.06%, available P (Spectro) 8.4 ppm, and exchangeable K 0.49 meq%. The soil type was Entisol with sandy loam texture. Two treatments were tested: (1) modern maize hybrid variety and (2) application of urea for the third time. The modern variety of maize consisted of four types, NK7328 (product of Syngenta), BISI18 and BISI2 (products of PT BISI), and P35 (product of Du Pont). The third application of urea comprised two levels: without the third-time application and with the third-time application of urea. All treatments were arranged factorially using a randomized, block design with three replications.

The 70 × 35 × 20 cm double-row planting pattern was used, which meant that the distance between two double rows was 70 cm, the distance within the double row was 35 cm, and the spacing in a double row was 20 cm. The plot size of each treatment was 455 × 200 cm^2, and with such a plot size, three double rows of maize were planted in each plot with one single row in each edge of the plot. The planting orientation was east–west.

The plants were fertilized with basic urea fertilizer and NPK (nitrogen, phosphor, potassium) Phonska (15-15-15) at doses of 150 and 190 kg/ha, respectively. Furthermore, the first supplementary fertilizer was applied when the plants were at 35 days after planting (DAP) with 200 and 190 kg/ha doses of urea and Phonska, respectively. A 150 kg/ha dose of urea was applied for the third time at tasseling (56 DAP). Weekly irrigation water was obtained from a nearby small river. The maintenance of the crops, such as mechanical weeding, was done before the first supplementary fertilizer application. A systemic fungicide (Tebukonazol + Trifloksistrobin) was applied at 70 DAP to prevent the spread of an unidentified fungus that caused discoloration of the lower leaves.

The variables measured were plant height, number of leaves, and interception of sunlight by the plant canopy (using AccuPAR/LAI Ceptometer LP-80, METER Group, Inc. USA) at tasseling. The

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crop yield and its components, such as cob length, cob weight, number of rows of seeds in a cob, weight of 1000 seeds, and weight of sundried seeds per cob and per plot, were measured after the cobs were sundried for 2 days without husk and shank. Analysis of variance for all collected data was run on Minitab 15, and correlation analyses were performed in Microsoft Excel.

3. Results and discussion

No rain occurred during the period of the experiment, and therefore water for the plants was obtained from the weekly irrigation water. The plants received sufficient water during the early vegetative stage, but after 6 weeks, the plants started to experience slight wilt in the top leaves on every sixth day after irrigation. The maximum temperature recorded during the experimental period was 37°C with a minimum of 29°C. All the plants also experienced a minor unidentified fungus disease attack starting from 70 DAP, which caused discolouring of lower leaves and could also affect yield and yield components.

Table 1. Effects of maize variety and the third application of urea on some parameters measured at tasseling and harvest.

	Measured variables				
Treatments	Plant height (cm)	Leaves number	Leaf angle (°)	Intercepted light (%)	Stover weight (ton/ha)
Variety					
NK7328	233.2	16.9	31.5 a	96.0 a	5.1
BISI18	236.0	15.9	32.0 a	95.1 a	4.6
BISI2	241.0	16.3	23.6 b	91.8 b	4.8
P35	235.4	15.6	30.7 a	96.9 a	4.6
Fertilizer					
With the third application of urea	238.5	16.3	29.8	95.1	5.0
Without the third application of urea	234.6	16.1	29.1	94.8	4.6

Mean values within a column in the same treatment followed by different letters are significantly different at $P < 0.05$ according to Tukey's range test.

All the tested modern maize hybrid varieties performed similarly in terms of plant height and leaf number at tasseling (table 1). This is a common result because modern maize hybrid varieties have small genetic variations, and their performance is affected mainly by the growing environment. However, in terms of leaf angle (the third leaf down from the flag leaf), the narrowest angle (23.6°) was recorded in BISI2 variety, which was much lower than that of the other three types as presented in table 1. This showed that BISI2 had the most erect or upright leaves, and therefore its population density had the highest possibility to be improved. With the current double-row planting pattern, the achieved population density was 98,000 plants/ha. The plant height, leaf number, leaf angle, and intercepted light by canopy were not affected by the third application of urea. This was obvious because urea was applied at the end of the vegetative stage (tasseling) and the target of the fertilizer application was the yield, not the growth parameters.

The third application of urea did not have a significant effect on light interception, but the canopy of the three maize varieties, P35, NK7328, and BISI18, intercepted ≥95% of sunlight, being the highest in P35. The other two varieties intercepted less but with no significant difference (table 1). The lowest light interception was recorded in BISI2, which was significantly different from that in the other varieties. A positive and significant correlation ($r^2 = 0.67$) was found between the leaf angle and light interception. At tasseling up to the grain-filling stage, the optimum sunlight interception for an optimum yield was suggested as 95% [8]. Maize hybrid varieties grown in a single-row pattern with a population density of fewer than 84,000 plants/ha have been reported to intercept less than 86% of sunlight at tasseling [9]. However, light interception can be improved by improving the population

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density [10], and the double-row pattern is an effective way to achieve this [6]. The canopy of P35, NK7328, and BISI18 grown at a population density of 98,000 plants/ha intercepted sunlight more than 95% at the tasseling stage, indicating that the population densities of these three varieties reached their optimum when planting a double-row pattern.

Plant stover (including leaves, leaf sheaths, stalks, and tassels) after harvest was not affected by either third application of urea or maize variety (table 1). The results showed that the four modern maize hybrid varieties tested in this study performed the same in terms of plant biomass after excluding their kernels (grains, cobs, and husks) as they had a very similar height and the number of leaves. The plant stover weight at harvest, which ranged from 4.6 to 5.1 ton/ha in this study, was within the range of data reported in an earlier study on eight varieties of modern maize at different planting dates [11]. The stover weight of those treated and not treated with the third application of urea was same because of the lowering rate of photosynthesis after tasseling and use of nitrogen to mainly provide more carbohydrate to the newly developed strong sinks, the ears [12].

Table 2. Effect of maize variety and the third application of urea on some cob parameters measured at shelling dry condition.

Treatments	Measured variables				
	Cob weight (g)	Cob length (cm)	Cob diameter (cm)	Grain rows per cob	Percentage of grain to cob (%)
Variety					
NK7328	158.3 a	13.9 a	4.2 a	16.3 a	81.6
BISI18	155.2 a	13.6 ab	4.2 a	15.9 ab	81.6
BISI2	134.4 b	11.9 b	3.7 b	13.2 b	82.1
P35	161.9 a	13.6 ab	4.3 a	16.3 a	83.4
Fertilizer					
With the third application of urea	163.1 a	13.8	4.2 a	15.7	82.5
Without the third application of urea	141.8 b	12.7	3.9 b	15.2	81.8

Mean values within a column in the same treatment followed by different letters are significantly different at P <0.05 according to Tukey's range test.

Significant differences were found in cob parameters (without husk and shank and measured at shelling dry condition), such as cob weight, cob length, cob diameter, and number of grain rows in a cob, but not the percentage of grains to cob. Overall, BISI2 produced the smallest cob size, which was significantly lower than that of the other three varieties, but with no significant difference (table 2). In terms of number of seed rows in a cob, the two BISI varieties produced a very similar number of seed rows. Plant biomass, especially after tasseling, has been reported to affect the cob parameters, but the sink–source ratio, especially the sink strength, determines the cob parameters the most [13]. In this study, the stover weight was not significantly different for the four varieties (measured at harvest), but the lowest cob parameter was measured in BISI2. It was possible that the sink strength of BISI2 was not as good as that of the other three varieties when grown under arid and non-optimum irrigation water conditions. The third application of urea affected the cob weight and cob diameter but not the cob length, number of grain rows in a cob, and percentage of grains to cob (table 2). The cob weight and cob diameter are parameters that determine the maize yield and are very much affected by the nitrogen status, especially during the grain-filling stage [14].

The grain weight per cob was affected by both variety and third application of urea. The P35 variety showed the highest grain weight but with no significant difference compared with those of NK7328 and BISI18, while the lowest was recorded in BISI2 (table 3). The BISI2 variety was supposed to produce two cobs per plant under favorable conditions. In this study, not all BISI2 plants produced two cobs per plant, and for those that produced two, only one had a length of more than 8 cm or cob diameter of more than 3.0 cm. Arid and non-optimum water irrigation conditions, especially after the end of the vegetative stage, might contribute to the non-optimum performance of the BISI2 variety. Slight water stress, especially during the critical stage of tasseling or cob formation, caused severe loss of maize yield [15]. In some cases, mild water stress could generate 13%–63% of maize yield [16]. High carbohydrate allocation was needed to produce more cobs during cob initiation [17], and this condition might not be achieved by the BISI2 variety at the experimental site with a limited source of water. However, the other three varieties performed better under such conditions compared with BISI2. This result can help in selecting the variety to be grown under arid conditions with a limited amount of irrigation water.

Table 3. Effect of maize variety and the third application of urea on yield and yield components.

Treatments	Measured variables			
	Grains weight per cob (g)[a]	1000 grains weight (g)	Grains weight per plot (kg)	Grains weight per ha (ton)
Variety				
NK7328	129.2 a	276.3 a	8.8 a	9.5 ab
BISI18	125.8 a	270.0 a	7.9 ab	8.8 ab
BISI2	105.2 b	255.0 b	7.4 b	8.2 a
P35	132.7 a	269.3 a	8.8 a	9.7 b
Fertilizer				
With the third application of urea	135.9 a	279.5 b	9.0 b	9.8 b
Without the third application of urea	110.5 b	256.1 a	7.5 a	8.2 a

Mean values within a column in the same treatment followed by different letters are significantly different at *P* <0.05 according to Tukey's range test.

Correlation analysis results showed that the grain weight per cob had significant and medium correlations with leaf angle (r^2 = 0.57), light interception by canopy (r^2 = 0.50), and number of grain rows per cob (r^2 = 0.67), and high correlations with cob length (r^2 = 0.76), cob weight (r^2 = 0.97), and cob diameter (r^2 = 0.87). Light interception by plants' canopy had a better correlation with grain weight per cob compared with the leaf angle. An earlier study showed that the grain yield of maize increased with the increase in light interception by the canopy of maize grown in a narrow row [4]. A correlation value of 0.70 was reported for the relationship between grain yield and light interception, which was higher than the results reported in this study. Location differences that lead to sun angle differences may contribute to the different values of the relationship. The positive and significant correlation among grain weight per cob, cob length, and number of grain rows per cob has also been reported earlier [18], with slightly higher correlation values in this study.

The smaller cob size in BISI2 resulted in lower grain yield per plot compared with the other three varieties, but with no significant difference compared with BISI18. The positive and medium correlation values between grain yield per plot and cob diameter (r^2= 0.72) as well as with cob length (r^2= 0.60) contributed to this result. Less light interception by canopy at the grain-filling stage might also contribute to the less yield in BISI2 compared with the other three varieties. Grain yield per plot had a positive but nonsignificant correlation (r^2 = 0.40) with light interception by plant canopy. The third application of urea increased the grain weight per cob by 18.7% and the grain weight per plot by 21% compared with those resulting from crops that did not receive a third application of urea. This result was in line with the earlier finding that nitrogen affected the yield of modern maize hybrid varieties [13]. Modern maize that experienced nitrogen deficiency, especially during the grain-filling stage, yielded less compared with varieties having sufficient nitrogen. Furthermore, sufficient nitrogen during the grain-filling stage was able to maintain photosynthesis capacity of the maize leaves [19]. The weight of 1000 seeds treated with a third application of urea, which was around 9% higher compared with those that did not receive a third application of urea, contributed to the higher yield.

8. Conclusion and suggestions

Maize varieties grown in a double-row pattern with a leaf angle of less than 30°, such as in BISI2, intercepted less than 95% of sunlight at tasseling. Less light interception coupled with a smaller cob size in BISI2 resulted in a lower yield compared with those in P35, NK7328, and BISI18 varieties. Yield of maize grown in an arid area with limited irrigation water improved by 21% when urea was applied for the third time at a rate of 150 kg/ha. These results indicated that BISI2, as a modern hybrid variety, performed less optimally in an arid area with less optimal irrigation water. To improve the yield of maize in a high population density, urea should be applied for the third time at tasseling. Further studies are needed to estimate the economic benefits of applying urea for the third time and improving BISI2 population density so that the canopy can intercept at least 95% of sunlight at tasseling.

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