Evaluation of yield and agronomic components of three-way cross maize hybrids under low-light environment

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Abstract. The development and the use of low light tolerant varieties is one of the technologies to overcome the limitations of hybrid maize in the land with the low-light condition. The objectives of the study were to determine the effect of shading/low light intensity on the growth and production of three-way cross maize hybrid, as well to generate hybrid variety that is tolerant to the shade stress condition. The research was conducted under two different environmental conditions, i.e. Screen House environment with 35% of paranet shading condition, and normal environment condition at Indonesian Cereals Research Institute experimental station from July to October 2018. The research was arranged in a Randomized Block Design (RBD) with three replications. The research material consisted of nine three-way crosses (STJ01-STJ09) and two check varieties (Bima-19 and P35). The results indicated that as many as four genotypes performed high yield under 35% shading condition i.e. STJ01, STJ02, STJ06 and STJ07 which yielded 5.60; 6.55; 5.87 and 6.15 t/ha respectively. Correlation analysis indicated various traits have a direct effect on grain yield i.e. ear weight, kernel net weight, ear length, number of kernels per row and kernel weight per ear. As for shading condition, the positive correlations were found for ear weight, ear length, number of kernels per row and kernel weight per ear characters.

1. Introduction
Maize is the second most important food source in Indonesia after rice. Maize is a strategic commodity and has high economic value, this is because apart from being the main source of carbohydrates and protein after rice, they are also used as an industrial raw material for animal feed and household. The need for maize continues to increase along with the increasing rate of population growth and the increasing need for food and feed. The efforts to increase national maize production were done by intensification (increased productivity) and extensification (area expansion). One of the efforts to increase maize production through intensification programs is by assembling new superior varieties.

One of the hybrid varieties that can potentially be developed as intercrops in plantations is the three-way cross maize hybrid. The three-way cross is one of the methods to form maize hybrids involving three parents. The female parent used in the three-way cross hybrid is a single-cross hybrid while the male parent is a pure line (inbred line) for example (A x B) x C [1]. The advantages of the three-way cross hybrid maize varieties are: (1) The yield of the seed produced is higher than that of a
single cross, so the price of the seeds become cheaper and more affordable to farmers, (2) Its F1 derivatives can be replanted with lower production than the single-cross counterparts.

One of the efforts to increase the production through the extensification program is by the expansion of maize planting areas utilizing marginal lands. Intercropping can be used as an alternative effort to utilize land optimally. According to Wijaksono and Navastra [2], the rate of change in food crops land to other types of plantations reached 19,206 ha/year. The area of palm plantations in Indonesia in 2016 was estimated to reach 11.67 million hectares (ha). Meanwhile, the area of rubber plantations reached 3.6 million ha. As for teak and coconut commodities, the planting area is 2.45 million ha and 3.88 million ha, respectively [3].

The main problem of growing maize as an intercrop plant in the plantation is the low-light condition because of the tree canopies. Maize one of the C4 plant is sensitive to the low-light conditions. The light received by maize plants, both intensity and quality, affects plant growth. The low-light intensity condition can cause the decrease in photosynthetic activity and the reduction of photosynthetic enzymes that act as catalysts in CO2 fixation [4]. Light intensity and the length of shade are the limiting factors in optimizing production. Shade stress can cause maize stems to become tall and thin, reduced number of leaves and smaller cobs [5]. In addition, shade can also alter the solar radiation received by plants both in intensity and quality so that it affects plant photosynthesis. Based on the challenges faced by low light grown maize, it is necessary to conduct research on the selection of genotypes of three-way cross maize with high yield and shade tolerant.

2. Methodology
The study was conducted at Screen House and Experimental field in Indonesia Cereal Research Institute, Maros, South Sulawesi, in June - October 2018. The research was conducted under different environmental conditions, i.e Screen House environmental with 35% paranet shading condition, and normal environment condition at Indonesian Cereals Research Institute experimental station. The research was arranged in a Randomized Complete Block Design (RCBD) with three replications. The materials used were nine three-way cross hybrids (STJ01-STJ09) and two check varieties (Bima-19 and P35).

| Num. | Genotype | Parents | Remarks |
|------|----------|---------|---------|
| 1    | STJ01    | B11209/MR14/MAL03 | three-way cross |
| 2    | STJ02    | B11209/MR14/G102612 | three-way cross |
| 3    | STJ03    | CLYN231/B11209//MAL03 | three-way cross |
| 4    | STJ04    | CLYN231/B11209/G102612 | three-way cross |
| 5    | STJ05    | CY7/MR14//MAL03 | three-way cross |
| 6    | STJ06    | CY7/MR14//NE19008 | three-way cross |
| 7    | STJ07    | B11209/MAL03//CLYN231 | three-way cross |
| 8    | STJ08    | B11209/MAL03/G102612 | three-way cross |
| 9    | STJ09    | 1044-14/NE19008//CLYN231 | three-way cross |
| 10   | STJ10    | BIMA19 | STJ/CEK01 |
| 11   | STJ11    | P35 | STJ/CEK02 |

The Screen house test for shade treatment and field for treatment without shade were done in a plot of 2.4 m x 1.4 m with a plant spacing of 70cm x 20cm. Each of the genotypes planted consisted of 2 lines per number. Each row consists of 12 plants with a population of 24 plants per plot. Planting was done by making planting holes in the soil, 2 seeds per planting hole. Before planted, the seeds were treated with Saromyl 355SD®, and the planting holes were treated with Carbofuran 30% with the dose of 15 kg/ha each to prevent the pests and diseases. The first fertilization was done at 7-10 das (days
after sowing) with 100 kg/ha of urea and 350 kg/ha of NPK. The fertilizers were applied by making holes around 5-8 cm away from the plant and closing it back once applied. The second fertilization was done at the age of 30-35 days with 200 kg/ha of urea. Second fertilizer was applied similarly to the first fertilization. The observed parameters were ear weight, 1000 kernel weight, kernel percentage, ear length, kernels/row, number of row/ear, kernel weight/ear, ear diameter, and yield. Variance analysis was conducted to assess the response of genotypes at different environments. In case genotype response significantly different, a further analysis was conducted by using LSD test at 95%. Statistical analysis was done by using CropStat Version 7.2.2007.3. Data analysis for correlation and path was done by involving TNAUSTAT and SPSS version 16 software.

3. Results and Discussion
Analysis of variance showed that the three-way cross maize genotypes had a highly significant effect on the characters of ear length, the number of rows per ear and kernel weight per ear. This shows the genetic diversity amongst them, which that parameters were dominantly controlled by genetic factors rather than environmental factors (Table 2).

Table 2. The mean squares of yield components and characters of three-way cross maize hybrids in two different locations

| Source of Variance   | DF | Ear Weight | 1000 Kernel Weight | Kernel % | Ear Length | Kernels/row | Number of Row/Ear | Kernel weight/Ear | Ear Diameter | Yield |
|----------------------|----|------------|-------------------|----------|------------|-------------|-----------------|------------------|--------------|-------|
| Environment          | 1  | 90.54**    | 131899**          | 0.45ns   | 294.43**   | 1181.1**    | 0.09**          | 203641**         | 3.94**       | 222.09* |
| Replication(Environment)| 4  | 3.71       | 5655.9            | 3.91     | 2.63       | 4.32        | 1.53            | 2264.61          | 0.07         | 13.32  |
| Genotype             | 10 | 0.30**     | 708.7**           | 10.14**  | 7.84**     | 14.8**      | 3.12**          | 926.63**         | 0.03**       | 1.28**  |
| Environment*Genotype | 10 | 0.36**     | 1168.2**          | 7.84**   | 1.16**     | 4.51**      | 0.41**          | 450.27**         | 0.02**       | 1.54**  |
| Errors               | 40 | 0.51       | 1217.7            | 6.81     | 1.39       | 8.14        | 0.88            | 342.45           | 0.03         | 1.42   |
| CV                   | 17.50% | 13.50%     | 3.40%             | 6.80%    | 8.30%      | 6.30%       | 11.60%          | 3.80%            | 16.00%       |

The results of the analysis of variance showed that the environmental treatment and genotype had a very significant effect, while the interaction between the environment and genotype did not significantly affect the length of corn ears. Table 3 shows that STJ02 genotype produced longer ear lengths and was significantly different from the Bima-19 as a check variety (a). The average ear length (19.70 cm) in normal environmental treatment (n0) is higher and significantly different from the low-light treatment (n1) with an average of 15.21 cm. The highest average of ear length was found in STJ02 genotype (22.02 cm), this is higher and significantly different from the Bima-19 comparison variety. The ear length will stop to increase if, during the flowering stage, the amount of light received by the plants is not sufficient [6, 7]. The environment that does not support the flowering period can cause the development of the ears to be ceased.

In addition, the genotype had a very significant effect, while the environmental treatment and the interaction between the environment and the genotype did not significantly affect for number of rows per ear trait. The result shows that all genotypes tested produced number of seeds per row that were not significantly different from the Bima-19 (a) and P-35 (a) as check varieties. The highest number of kernels per row was found in STJ11 with an average of 38.27 kernels and the lowest was STJ09 genotype with an average of 32.14 kernels. In normal environmental treatment (n0), the average number of kernels per row (38.73) was higher and significantly different from the low-light environment condition (n1) with an average of 29.85.
Table 3. The mean results of yield components and characters of the three-way cross maize hybrids in two different locations

| Genotype | Parents                          | Mean |                |                |                |                | TKW  | Kernel % | Yield |
|----------|----------------------------------|------|----------------|----------------|----------------|----------------|------|----------|-------|
| STJ01    | B11209/MR14/MAL03                | 16.85| 4.47           | 4.11           | 15.00          | 33.97          | 156.59| 262.96   | 76.36 | 7.40  |
| STJ02    | B11209/MR14/G102612              | 19.41| 4.53           | 4.41           | 14.34          | 34.20          | 178.4a| 264.24   | 78.04 | 8.16  |
| STJ03    | CLYN231/B11209/MAL03              | 17.05| 4.45           | 3.96           | 14.67          | 32.90          | 150.00| 278.73   | 78.16 | 7.39  |
| STJ04    | CLYN231/B11209/G102612           | 17.36| 4.50           | 4.05           | 16ab           | 32.77          | 169.12| 252.24   | 76.82 | 7.08  |
| STJ05    | CY7/MR14/MAL03                   | 17.10| 4.44           | 3.89           | 14.34          | 34.44          | 152.35| 257.38   | 76.41 | 7.12  |
| STJ06    | CY7/MR14/NEI9008                 | 16.25| 4.40           | 3.98           | 14.00          | 34.64          | 144.18| 254.81   | 77.60 | 7.39  |
| STJ07    | B11209/MAL03/CLYN231             | 17.27| 4.54           | 4.25           | 16ab           | 34.60          | 159.92| 248.13   | 79.10 | 8.13  |
| STJ08    | B11209/MAL03/G102612             | 19.03| 4.34           | 4.17           | 14.67          | 34.80          | 152.00| 242.05   | 76.68 | 7.39  |
| STJ09    | 1044-14/NEI9008/CLYN231          | 15.85| 4.56           | 3.78           | 16ab           | 32.14          | 146.47| 217.74   | 78.28 | 6.99  |
| STJ10    | BIMA19 (a)                       | 17.70| 4.60           | 4.21           | 14.67          | 34.47          | 169.54| 269.05   | 74.51 | 7.02  |
| STJ11    | P35 (b)                          | 18.13| 4.56           | 4.32           | 15.00          | 38.27          | 179.10| 265.93   | 78.39 | 8.16  |
| Mean     |                                 | 17.35| 4.47           | 4.07           | 15.00          | 33.83          | 156.56| 253.14   | 77.49 | 7.45  |

The results of the analysis of variance showed that the environmental and the genotype treatment had a significant effect, while the interaction between the environment and the genotype did not significantly affect the weight of kernels. It was shown that the STJ02 genotype produced the highest kernel weight per ear with an average value (178.40 grams) and was significantly different from the Bima-19 as a check (a). In normal environmental treatment (n0) the average weight of kernels per ear (215.33 g) is higher and significantly different from the low-light environment (n1) with an average of 104.24 g. The environmental treatment (shaded and non-shaded) significantly affected the characters of ear length, the number of rows per ear and the weight of kernels per ear. This shows that the environment can be used as a selection condition. The results of the analysis of variance show that genotype had a significant effect on the parameter number of rows per ear. This indicates that these parameters were dominantly controlled by genetic factors rather than controlled by environmental factors.

The positive correlation value indicates that the greater the variable, the greater the yield obtained, otherwise, the negative correlation value indicates that the lower the value of the variable, the lower the yield obtained. The phenotypic correlation coefficient provides breeders with important information about the relationship between the determinant characters on yield [8]. The variables that correlate significantly to the results, can be analysed for its direct and indirect contribution to the yield by using Path analysis. The results of the path analysis can be used to determine the morphological characters that have an influence on the yield of the three-way cross maize hybrid. The direct effect is the morphological character which gives a direct influence on the yield results without influencing other yield components. Path analysis is used to sort the genetic correlations between yields and characters related to yields as a direct or indirect effect [9].

The morphological characters measured that have a highly positive correlation with the yield are the ear weight, kernel percentage, ear length, the number of kernels per row and the weight of kernels per plant with the correlation coefficient (r) of 0.831**, 0.699**, 0.427**, 0.434** and 0.407** respectively. The results of the path analysis show that a significant direct effect was found on the ear weight character. The direct effect of other characters is either positive or negative with a low value. Direct selection can be done on the weight of the ears. Based on the coefficient values of the path analysis, it can be inferred that out of the eight selected characters analyzed, the weight of the ears was
a dominant character that determines the yield. This is indicated by the correlation coefficient values between the weight of the ears and the yield \((r = 0.83**\)).

**Table 4.** Path analysis of the influence of morphological characters on yield under normal environmental conditions.

| Variable                      | Direct effect | Indirect effect | Total  |
|-------------------------------|---------------|-----------------|--------|
|                               | Ear weights | 1000 kernels | Kernel % | Ear length | Kernels per row | Row per ear | Kernel weight per plant | Ear diameter |        |
| Ear weights 1000 kernels      | 1.138       | -   | 0.141 | -0.092 | 0.171 | -0.091 | -0.032 | -0.171 | -0.232 | 0.831** |
| Kernel %                      | 0.342       | 0.469 | -   | 0.000 | 0.061 | -0.045 | -0.243 | -0.111 | -0.178 | 0.295ns |
| Ear length                    | -0.177      | 0.595 | 0.000 | -0.161 | -0.031 | 0.177 | -0.110 | 0.084 | 0.699** |
| Kernels per row               | 0.523       | 0.604 | 0.065 | -0.088 | -0.080 | -0.067 | -0.190 | -0.140 | 0.427** |
| Row per ear                   | -0.173      | 0.596 | 0.090 | -0.031 | 0.149 | -0.040 | -0.201 | 0.045 | 0.434** |
| Kernel weight per plant       | 0.382       | -0.096 | -0.218 | -0.082 | -0.056 | 0.018 | -0.028 | 0.196 | 0.115ns |
| Ear diameter                  | -0.323      | 0.602 | 0.117 | -0.060 | 0.190 | -0.108 | 0.033 | -0.043 | 0.407** |
|                               | 0.562       | -0.470 | -0.108 | -0.026 | -0.080 | -0.014 | 0.133 | 0.025 | -      | 0.022ns |

Residue = 0.2997
Remarks: **= highly significantly different at 99% confidence level; *= significantly different at 95% confidence level; ns= not significantly different.

The correlation analysis between characters for all morphological characters measured (eight characters) under low-light environment conditions shown that the morphological characters that have a highly positive correlation with the yield are the ear weight, ear length, the number of kernels per row and kernels weight per plant with the correlation coefficient \((r\) of 0.927**, 0.497**, 0.645** and 0.853**, respectively. The results of the path analysis on the low-light conditions show that significant direct effect was found on the character of the ear weights. The direct effect of other characters is either positive or negative with a low value. Direct selection can be done on the weight of the ears. Based on the coefficient value of the path analysis, it can be interpreted that out of eight characters observed, the ear weight dominantly independently determines the yield obtained. This is indicated by the value of the correlation coefficient between the ear weight and the yield \((r = 0.927**\)).

**Table 5.** Path analysis of the influence of morphological characters on the yield under low-light conditions.

| Variable                      | Direct effect | Indirect effect | Total  |
|-------------------------------|---------------|-----------------|--------|
|                               | Ear weights | 1000 kernels | Kernel % | Ear length | Kernels per row | Row per ear | Kernel weight per plant | Ear diameter |        |
| Ear weights 1000 kernels      | 1.277       | -   | 0.037 | -0.195 | -0.209 | 0.044 | -0.005 | 0.023 | -0.045 | 0.927** |
| Kernel %                      | 0.075       | 0.624 | -   | -0.190 | -0.159 | 0.022 | 0.006 | 0.012 | -0.039 | 0.350* |
| Ear length                    | 0.330       | -0.755 | -0.044 | -0.000 | -0.003 | -0.002 | -0.013 | 0.058 | -0.339* |
| Kernels per row               | -0.324      | 0.824 | 0.037 | -0.092 | -0.038 | 0.018 | 0.017 | -0.021 | 0.497** |
| Row per ear                   | 0.085       | 0.850 | 0.007 | -0.013 | -0.145 | 0.025 | 0.011 | 0.003 | 0.645** |
| Kernel weight per plant       | -0.068      | 0.085 | 0.020 | -0.013 | -0.032 | 0.000 | 0.003 | -0.018 | 0.057ns |
| Ear diameter                  | 0.024       | 1.225 | 0.038 | -0.188 | -0.228 | 0.040 | -0.007 | -0.050 | 0.853** |
|                               | -0.075       | 0.770 | 0.040 | -0.257 | -0.090 | -0.004 | -0.016 | 0.016 | -0.384ns |

Residue = 0.1442
Remarks: **= highly significantly different at 99% confidence level; *= significantly different at 95% confidence level; ns= not significantly different.
Based on the correlation analysis under normal environmental conditions, the ear weight, kernel percentage, ear length, number of kernels per row, and kernels weight per ear have a highly significant positive correlation to the yield under normal light conditions. The ear weight and ear length had a significantly positive direct effect on yield per hectare with the coefficients of path analysis of 1.138 and 0.323 respectively. This indicates that the higher the value of the ear weight and ear length will contribute to the higher value of yield per hectare.

Based on the correlation analysis under low-light conditions, the ear weight, ear length, number of kernels per row, and kernels weight per ear have a highly significant positive correlation to the yield under the low-light condition. The ear weight has a significantly positive direct effect on yield per hectare with the coefficients of path analysis of 1.277. This shows that the higher the value of the ear weight, the yield will likely also be increased. A study by Fatmawati and Suriani et al. [10, 11] is also reported that the ear weight had a significant direct effect on maize yield under stress conditions.

4. Conclusion
The results of low light maize tolerance under two environments indicated that as many as four genotypes performed high yield under 35% shading condition i.e. STJ01, STJ02, STJ06 and STJ07 which yielded 5.60; 6.55; 5.87 and 6.15 t/ha respectively. Correlation analysis indicated various characters provides a direct effect on yield i.e. ear weight, kernel net weight, ear length, number of kernels per row and kernel weight per ear. As for the low-light condition, a positive correlation was found for ear weight, ear length, number of kernels per row and kernel weight per ear characters.

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