Yield Performance of Shade Tolerant Soybean Cultivars under Shaded Environment at Various Planting Densities

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Abstract. Expanding soybean [Glycine max (L.) Merr.] production under sub-optimum environment faces the problem of production under a shaded environment. The study aimed to evaluate the yield performance of shade-tolerant soybean cultivars under shaded environment conditions at various planting densities and to determine its related traits. A nested design field experiment was conducted at Banjar Sub-district, Pandeglang District, Banten Province Indonesia (lat. 6.37° S, long. 106.11° S) during the dry season from April to July 2019. Two field conditions, under coconut and banana plantation, which were identified as light-shaded (10-20 % shaded) and deep-shaded (40-50 % shaded) were used as main plots. Three soybean cultivars, Dena-1, as identified as shade-tolerant soybean cultivar, Detap-1 and Devon-1 were arranged at each environment with a single row (40 x 20 cm; normal density; 12.5 plants m$^{-2}$) or double row (30 x 20 x 50 cm; high density; 14.5 plants m$^{-2}$). Research results showed that seed yield decreased from 248 g m$^{-2}$ to 205 g m$^{-2}$ by the difference of shading. The yield decrease was due to the decrease of total biomass (TDW), branch number, node number, pod number, and seed number, and stomatal density ($N_{stoma}$) without any change in harvest index (HI) and guard cell length ($L_{guard}$). In plant arrangement, a better seed yield and TDW were resulted from normal density as compared to high density. Under the deep-shaded condition, Dena-1 under normal density (230 g m$^{-2}$) was superior in seed yield but declined significantly when it was grown under high density (161 g m$^{-2}$). Based on the above results, combining shade-tolerant soybean cultivar (Dena-1) and planting density (single row; 12.5 plants m$^{-2}$) is recommended to maintain soybean seed yield under a shaded environment.

1. Introduction

Soybean [Glycine max (L.) Merr.] is one of the major oilseed crops, and is used often as protein meal and vegetable oil throughout the world[1][2][3]. Soybean production expansion faces the problem in production under sub-optimum conditions, such as secondary crops under-stories plantations or intercropped with tall crops. On the other side, some other possible ways to improve soybean production is through combining high yielding soybean cultivars, appropriate planting density, and other agricultural practices. However, soybean is grown at high densities, in forest understories/ plantations, or intercropped with tall crops are exposed to low light intensity or shade [4].
Light plays an important role in the development and performance of a plant's growth and development [4][5]. Shaded environments induce a series of morphological changes and consequently express shade avoidance characteristics, such as increased stem elongation and reduced stem diameter [5], which could reduce crop productivity [6].

Indonesia, with a huge area of plantation such as palm oil, palm, rubber-plant, has the potential for soybean production expansion. Besides, some soybean cultivars, which one of them is claimed to have a good tolerance to shade the environment, potentially to be used for production under a shaded environment. Therefore, the study aimed to evaluate the yield performance of shade-tolerant soybean cultivars under shaded environment conditions at various planting densities and to determine its related traits.

2. Material and Methods

2.1. Cultivar and agronomical practices
A nested design field experiment was conducted at Banjar Sub-district, Pandeglang District, Banten Province Indonesia (lat. 6.37° S, long. 106.11° S) during the dry season from April to July 2019. The experimental field condition was identified as a shaded environment under coconut and banana plantation. Two field conditions, which were identified as light-shaded (10-20 % shaded; N1) and deep-shaded (40-50 % shaded; N2) were used as main plots. Three soybean cultivars, namely Dena-1, as identified as shade-tolerant soybean cultivar, Detap-1 and Devon-1, were arranged at each environment with single row (40 x 20 cm; normal density; 12.5 plant m$^{-2}$; D1) or double row (30 x 20 x 50 cm; high density; 14.5 plant m$^{-2}$; D2). Planting density and cultivars were used as sub-plots.

On 23 April 2019, seeds were sown and grown under field conditions with three replications using 2.4 x 6 m plots. After seedling emergence, plants were thinned to one plant per hole. The soil was fertilized with 5 g m$^{-2}$ of N, 1.18 g m$^{-2}$ of elemental P, and 6.22 g m$^{-2}$ of elemental K with urea, calcium superphosphate, and potassium chloride, respectively. Regional recommended management programs were employed for irrigation and pest control to optimize growth conditions.

2.2. Plant growth and development
Plant developmental stages were recorded following the protocol described by [7]. At the flowering stage (R1), plant height and branch number were observed. Two plants from each plot were taken and oven-dried at 80 °C for 48 hours, and aboveground total dry weight (TDW) was recorded.

2.3. Stomatal morphology
Stomatal morphological traits were measured following the method described by [8][9]. Stomatal density ($N_{stoma}$) and guard cell length ($L_{guard}$) were measured in the abaxial part of the leaf using Suzuki’s Universal Micro-Printing method (SUMP, Tokyo, Japan). Two leaves from two plants per plot were taken from the upper most-fully expanded-matured leaf for six weeks after planting. $N_{stoma}$ and $L_{guard}$ were determined by analyzing digital images of leaves; images were obtained by placing the disk of printing directly on a microscope slide and captured at 400-fold (10 x 40) magnification. Stomata calculation and length measurement were established using the segmented line tool of ImageJ (National Institute Health USA) as described in [8][9].

2.4. Yield and yield components
At the maturity stage (R8), seed yield and yield components, node number, pod number, TDW, and harvest index (HI) were determined by harvesting four plants per plot. Further, Seeds were counted and weighed, and moisture content was determined by a seed moisture meter. Seed yield was expressed as 14 % water content. Seed size was expressed as 100 seed weight (100SW),
Besides, Plant height and branch number were also observed. Internode length was calculated as plant height divided by main stem node number.

2.5. Data analysis
To better understand the relationship between seed yield and yield components in N1 and N2 as well as D1 and D2, correlation analysis was performed between seed yield with yield components. A one way ANOVA analysis using MINITAB 16 was performed to evaluate the effect of shaded environment, planting density and cultivar, and its interaction on yield and yield components, and followed with a Tukey’s test.

3. Results and Discussion
3.1. Plant growth and development
All three were flowering mostly at the same time. All cultivars reached R1 [7] at 34 days after sowing. In general, plant height at R1 across the cultivars and planting densities was lower under deep-shaded compared to that of the height under light-shaded (Fig. 1A). The plant height at normal density seemed to be similar to that of high density (Fig. 1B). Across the environment and density, Detap-1 was shorter than two other cultivars (Fig. 1C).

![Figure 1. Plant height of soybean cultivars at R1: (A) light-shade or deep-shade environment, (B) normal or high planting density, (C) three cultivars across the environment and planting density. N1= light-shaded, N2= deep-shaded; D1= normal density, D2= high density; V1= Dena-1, V2= Detap-1, V3= Devon-1.](image)

The branch number at R1 across the cultivars and densities was smaller under deep-shaded than that of light-shaded (Fig. 2A). Variation in branch number occurred between cultivars. Dena-1 was the highest in branch number development at R1 followed by Devon-1 (Fig. 2C).

![Figure 2. Branch number of soybean cultivars at R1: (A) light-shade or deep-shade environment, (B) normal or high planting density, (C) three cultivars across the environment and planting density. N1= light-shaded, N2= deep-shaded; D1= normal density, D2= high density; V1= Dena-1, V2= Detap-1, V3= Devon-1.](image)
Besides, the TDW of cultivars grown under deep-shaded was smaller than that of light shade (Fig 3). Similarly, the biomass accumulation of cultivars grown at high density was smaller than the biomass produced at normal density. The above results, smaller branch numbers, and TDW under deep shaded as well as high density affected soybean growth and development.

![Figure 3](image_url)

**Figure 3.** Aboveground total dry weight (TDW) of soybean cultivars at R1: (A) light-shade or deep-shade environment, (B) normal or high planting density, (C) three cultivars across the environment and planting density. N1= light-shaded, N2= deep-shaded; D1= normal density, D2= high density; V1= Dena-1, V2= Detap-1, V3= Devon-1.

### 3.2. Stomatal Morphology

Stomatal morphology was one of the important traits determined by gas exchange activity in plants [9] and adaptation to environments [8]. Across three cultivars, the average of $N_{stoma}$ tended to be similar in each environment at different planting densities. However, the variation between cultivars became wider under high planting density (Fig. 4A).

Under light-shaded, the $L_{guard}$ was shorter in high density as compared to that of in normal density (Fig. 4B) but seemed to be shorter under deep-shaded. Similarly, wider variation in the length of guard-cell between cultivars has also occurred under deep-shaded. However, in this experiment, there was no correlation between seed yield with stomatal morphology. A different result was reported by [8] where tropical soybean cultivars have a better adaptation to high-temperature stress with better stomatal morphology.

![Figure 4](image_url)

**Figure 4.** (A) Stomatal density, and (B) guard cell length of three soybean cultivars at six weeks after planting under light-shade or deep-shade environment at two planting densities. N1= light-shaded, N2= deep-shaded; D1= normal density, D2= high density.
3.3. Yield and yield components

Across three cultivars and planting density, seed yield was lower in deep-shaded (207 g m⁻²) than that produced under light-shaded (238 g m⁻²) (Table 1). The seed yield reduction in deep-shaded was due to smaller production rather than the change of HI. The TDW in deep-shaded was 15% smaller as compared to the biomass produced under light-shaded (Table 1). However, the HI seems to be similar between the two environments.

Table 1. Yield, above-ground dry weight (TDW), and harvest index (HI) of three soybean cultivars under two shaded environments and planting densities.

| Shade Environment | Planting Density | Cultivar   | Yield (g m⁻²) | TDW (g m⁻²) | HI  |
|-------------------|------------------|-----------|---------------|-------------|-----|
| Light-shaded (N1) | Normal Density   | Dena-1    | 256           | 469         | 0.47|
|                   | D1               | Devap-1   | 304           | 524         | 0.50|
|                   | Avg.             |           | 279           | 494         | 0.48|
|                   | High Density     | Dena-1    | 186           | 340         | 0.47|
|                   | D2               | Devap-1   | 236           | 434         | 0.46|
|                   | Avg.             |           | 198           | 356         | 0.48|
|                   | Average          |           | 238           | 425         | 0.48|
| Deep-shaded (N2)  | Normal Density   | Dena-1    | 230           | 425         | 0.46|
|                   | D1               | Devap-1   | 205           | 354         | 0.50|
|                   | Avg.             |           | 219           | 395         | 0.48|
|                   | High Density     | Dena-1    | 161           | 280         | 0.50|
|                   | D2               | Devap-1   | 219           | 381         | 0.50|
|                   | Ave.             |           | 195           | 329         | 0.51|
|                   | Average          |           | 207           | 362         | 0.49|

Under light-shaded and normal density, seed yield of Devon-1 was the highest (304 g m⁻²) as compared to that of other cultivars, but declined significantly by 27% when it was grown under deep-shaded (Table 1). In contrast, seed yield of Dena-1 under light-shaded and normal density was not superior (256 g m⁻²), but declined smaller by only 10% (Table 1). Similar changes also occurred in biomass production. Cultivar Devap-1 produced 524 g m⁻² of biomass under light-shaded and normal density but decreased by 19% when it was grown under deep-shaded. Similarly, Dena-1 maintained the biomass from 469 g m⁻² under light-shaded and normal density to 425 g m⁻² under deep-shaded and normal density or was decreased by 9%. Besides, there was no change in HI for all cultivars grown under different shade conditions.

Seed yield of soybean grown at high density was lower in both light-shaded and deep-shaded as well. The average seed yield of three cultivars at light-shaded and high density was 238 g m⁻² and decreased to 195 g m⁻² under deep-shaded. The decline was also evident in biomass, where the TDW of cultivars under deep-shaded and high density was declined from 356 g m⁻² to 329 g m⁻² or decreased by 8%. The decrease of seed yield of cultivars grown under deep-shaded was in line with that of TDW, but not with the HI. The results indicated that deep-shaded affect the decrease of seed yield through the reduction of biomass which could be explained by the changes of yield component and other plant morphology that will be discussed later.

Plant height and branch number at the maturity stage were observed, and the result was provided in Fig. 5. Across the cultivars and planting densities, plant height was slightly smaller under deep-shaded as compared to the height under light-shade. In general, variation between cultivars occurred. Cultivar Dena-1 tended to be taller in each environment and planting density as compared to two others (Fig. 5A). The decline in branch number was more evident due to
greater shaded and higher density as well. In general, cultivars grown under deep shaded as well as high density tended to produce less branch number (Fig. 5B).

![Figure 5](image_url)

**Figure 5.** (A) Plant height, and (B) branch number per plant of three soybean cultivars at maturity stage under light-shade or deep shade environment at two planting densities. N1= light-shaded, N2= deep-shaded; D1=normal density, D2=high density. N1= light-shade, N2= deep-shade; D1=normal density, D2=high density; V1=Dena-1, V2=Detap-1, V3=Devon-1.

Seed yield was determined by biomass accumulation (TDW) and partitioning (HI) and closely associated with yield components [1][10][11]. Under a shaded environment, soybean growth could be altered thus affecting yield and yield components [5]. In this experiment, the decline of yield components was evident. Node number per plant was reduced from 28.8 under light-shaded to 21.8 under deep-shaded and was also followed by pod number and seed number from 65.0 to 55.9 per plant, and from 137 to 119 per plant, respectively, under light-shade to the deep-shade environment (Table 2).

Under a deep-shaded environment, the node number and pod number were better at normal density as compared to that at high density. The Node number and pod number were decreased from 27.4 and 58.9, respectively at a normal density to 21.8 and 52.9, respectively at high density (Table 2). Planting density affected not only node number and pod number but also seed number. The seed number under deep-shade was decreased from 125 at a normal density to 113.6 at a high density (Table 2).

There was an inconsistent result in seed size caused by the shaded environment and planting density. However, internode length tended to be longer under deep-shaded as compared to that under light-shaded, as well as at high-density as compared to that at high density. The longer internode under deep-shaded and higher planting density indicated a response of cultivars to the environment on morphology. These results were in line with that reported by [5][12] where some morphological changes on plants enabled the crop to intercept relatively more light.
Table 2. Yield components of three soybean cultivars under two shaded environments and planting densities.

| Shade Environment | Planting Density | Cultivar | Node number (plant⁻¹) | Internode length (cm) | Pod number (plant⁻¹) | Pod/Node | Seed number (plant⁻¹) | 100 SW (g) |
|-------------------|------------------|----------|------------------------|-----------------------|----------------------|----------|-----------------------|-------------|
| Light-shaded      | Normal           | Dena-1   | 29.1                   | 5.6                   | 68.8                 | 2.4      | 136.3                | 13.1        |
| (N1)              | High             | Dena-1   | 28.7                   | 5.5                   | 60.3                 | 2.1      | 122.2                | 12.1        |
|                   | Average          |          | 28.8                   | 5.4                   | 65.0                 | 2.2      | 137.0                | 12.5        |
| Deep-shaded       | Normal           | Dena-1   | 30.8                   | 5.3                   | 66.3                 | 2.2      | 128.4                | 12.4        |
| (N2)              | High             | Dena-1   | 20.0                   | 6.0                   | 47.6                 | 2.4      | 89.8                 | 13.8        |
|                   | Average          |          | 21.8                   | 5.8                   | 52.9                 | 2.4      | 113.6                | 13.6        |
|                   |                  |          | 24.6                   | 5.52                  | 55.9                 | 2.3      | 119                  | 12.9        |

3.4. Relationship between yield and yield components
Seed yield was positively correlated with TDW (R²= 0.96) (Fig. 6A). This result indicated that under a shaded environment, seed yield could be maintained by the ability of cultivars on producing biomass. Besides, TDW was also positively correlated with pod number (R²= 0.78) as well as its correlation with seed number (R²= 0.72) (Fig. 6B and C). The results showed that TDW was a good trait determining yield and yield components. The biomass accumulation could be altered under a stress environment that affects yield performance [13][11].

![Figure 6](image) Correlation between (A) yield with above-ground dry weight (TDW), (B) TDW with pod number per plant, and (C) TDW with seed number per plant of three soybean cultivars under light-shade or deep shade environment at two planting densities. N1= light-shade, N2= deep-shade; D1=normal density, D2=high density.

4. Conclusion
Seed yield was decreased by the increase of shade intensity. Under light-shaded, a better seed yield and biomass were resulted from normal density as compared to that of high density. Under the deep-shaded condition, Dena-1 under normal density was superior in seed yield but declined
significantly when it was grown under high density. Combining shade-tolerant soybean cultivar (Dena-1) and planting density (single row; 12.5 plant m$^{-2}$) was recommended to maintain soybean seed yield under a deep-shaded environment.

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