Soybean varieties tolerance to intercropping with maize

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Abstract. There is no available information in determining soybean varieties that shows tolerant when intercropped with maize. The objective of this study was to determine soybean varieties suitable for intercropping, based on changes in plant growth and yield when intercropped. The field experiment was conducted from October 2019 to February 2020 based on RCBD with 2 factors. The first factor was soybean with 16 national varieties. The second was cropping systems i.e., monoculture and intercropping. Morphology and yield data were observed and subsequently analysed based on performance difference (D) of each parameter between intercropping and monoculture. Tolerance level to cropping systems with maize was grouped based on the yield-based and selection index calculations. The results showed that different cropping systems affected morphological and yield parameters on 16 tested soybean varieties. Seven varieties i.e., Derap 1, Devon 1, Devon 2, Demas 1, Dena 1, Dena 2, and Wilis were grouped as tolerant to intercropping with maize. Among these, Derap 1 was the most tolerant variety.

1. Introduction

Soybean (Glycine max L.) is the third most important crop in Indonesia [1]. In the last decades, soybean consumption in Indonesia has increased significantly, and currently becomes one of the national strategic commodities. Soybean is also known as source of protein with high nutrition contents such as isoflavone, saponin, fatty acid and fiber [2]. On average, our national consumption of soybean reached 2.3 million tons per year. However, we are still lacking soybean production, in which in the last 5 years, the national production was only below one million tons per year, or only 43% of the soybean demand [1].

Soybean production, its productivity and the planted area were fluctuated from 2014 to 2018. While there was an 82.39% increase of the planted area in 2017-2018, its productivity on the other hand, showed a drop of 4.62% [1]. Intercropping is believed beneficial in minimizing the competition on land use for production of other crops. Soybean-maize intercropping is projected to form an integrated agriculture system consisting of four pillars i.e., production, stability, food security and sustainability [3].

In intercropping system, above and below ground competitions affect plant growth. One of the above ground factors which important is the light availability. In intercropping system of soybean-maize, the maize shading reduced the light intensity received by soybean, as its morphological stature is lower. Therefore, a response or adaptation of soybean to maize shading are of important index for
those who selecting soybean varieties suitable for maize-soybean intercropping system [4]. Study on the variability of intercropping-tolerance among intercropped crops is therefore one of great benefit for selecting high-yield soybean varieties under the intercropping system [5]. The objective of this study was to determine soybean varieties suitable for intercropping, based on the changes in plant growth and yield characteristics when intercropped.

2. Methods

2.1. Site description

The field experiment was conducted at Rural Extension Center (Balai Penyuluhan Pertanian) of Seyegan, Sleman, Yogyakarta, Indonesia, (latitude: -07 deg 43 min 49.7621 sec, longitude: 110 deg 18 min 16.4783 sec). The soil was composed of silt loam with pH 6.5 with Nitrogen total (0.19%), Nitrogen availability (0.02%), Kalium availability (180 ppm), and P2O5 (131.50 ppm).

2.2. Experimental design

The research was arranged in RCBD with 2 factors and experimented from October 2019 to February 2020. First factor was sixteen soybean varieties, while the second factor was cropping systems i.e., monoculture and intercropping. In total, there were 32 treatment combinations (16 varieties × 2 cropping systems) with 3 replications (96 plots) applied in this research. We utilized a 5 m × 1 m plot size. Soil tillage was done and manured using chicken manure (10 ton ha⁻¹). Prior planting, soybean seeds were mixed with leguminosa inoculum (Legin®) (30 g 10 kg⁻¹ seed). The planting arrangement for monoculture followed a 20 cm ×20 cm with 2 seeds per planting hole and 20 cm ×100 cm spacing for soybean and maize, respectively. For intercropping, the soybean was planted between row with maize by 40 cm spacing and ratio of 1:2 (maize: soybean). For each monoculture and intercropping plot contained 220 (2 seeds×110 planting holes) and 100 (2 seeds×50 planting holes) plants, respectively. Soybean fertilizations were employed using Urea (50 kg ha⁻¹), TSP and KCl (each 100 kg ha⁻¹) [6], completed at planting time by spreading it around the planting hole. As for maize, the fertilizations were conducted at 1 week-after-planting (WAP) by using Urea (100 kg ha⁻¹), SP36 (50 kg ha⁻¹), and KCl (75 kg ha⁻¹). Additional Urea (150 kg ha⁻¹) and KCl (50 kg ha⁻¹) were applied at 4 WAP [7]. Watering was scheduled on 15-21, 25-35, and 56-63 day-after-plantings (DAPs). Harvesting was done when it reached physiological maturations, i.e., brown and falling leaf, pod and stem turned brown, and seed had fully contained.

2.3. Data analysis

Morphological data of stem diameter, plant height, and number of productive branches were obtained at certain schedules. Stem diameter was recorded at 7 WAP, whereas plant height and number of productive branches were measured and counted at 2, 4, 6 and 8 WAPs and harvesting time, respectively. Yield variables included the number of pod/plant, number of seed/plot, number of seed/plant, 100-seed weight and seed weight/plant were obtained at harvesting time. Sigmoid curve for growth based on plant height parameter was then constructed. The performance difference (D) of each parameter between intercropping and monoculture in all varieties, was calculated in a formula [14]:

\[ D = \left( \frac{\text{Intercropping-Monoculture}}{\text{Monoculture}} \right) \times 100\% \]

To screen soybean varieties tolerant to intercropping with maize, the sixteen soybean varieties were clustered into groups of tolerant and intolerant based on two measurements. The first was yield-based calculation. The variety was defined as tolerant if the yield on intercropping system (Ys) was higher than those of the average from sixteen varieties tested in both cropping systems. Secondly, the grouping was based on screening index. Six different screening indexes including stress tolerance index (STI) i.e. higher STI value was more tolerant [8]; stress susceptibility index (SSI) i.e. SSI value <1 was more tolerant [8]; tolerance (TOL) i.e. lower TOL value was more stable [9]; mean productivity (MP) i.e. higher MP value was more desirable [9]; geometric mean productivity (GMP) i.e. higher GMP value was more desirable [10], yield stability index (YSI) i.e. higher YSI value can be regarded as more stable [11], and yield index (YI) i.e. high value of YI will be suitable for stress condition [12], were evaluated. Only those with significant coefficient correlation at P<0.05 in both cropping systems were further employed to categorize the tolerance level based on similar criteria as
used for yield-based calculation. These analyses were conducted by using Microsoft Excel for Mac 2016 (Microsoft, USA).

3. Results and discussion

3.1. Morphological characters

Based on performance difference calculation (14), the 16 varieties were divided into 3 groups: a) low plant height-high stem diameter, i.e., Pangrango, Dena 1, Grobogan, Dega 1, Demas 1, Devon 1, Derap 1, and Gepak Kuning; b) low plant height-low stem diameter, i.e., Dena 2, Devon 2, Detap 1 and Mahameru; and c), high plant height-low stem diameter, i.e., Anjasmoro, Wilis, Deja 1 and Slamet (Table 1). Characters of varieties in Group a and b were contradictory compared to other studies [13], [14], [15], in which intercropping had increased plant height and decreased stem diameter. Varieties in Group c showed characters fairly in line with [13, 17] in which intercropping increased internode length (78.50 - 82.30%) at the expense of reducing stem diameter (-40.00 to -50.00%), even though its difference level for the same variable in this current research was high (0.68-2.10% and 0.83-15.75%, respectively). Cassal [16] reported that the increasing plant height in this group was due to the reduced light intensity as part of the shading effect, and thus reducing the photosynthetic-active-radiation (PAR) by 50.0 - 54.0%. This microclimate change was considered as the main driver for the difference of morphological parameters between cropping systems. We considered that the shading stress had occurred at low level. Therefore, the varieties did not respond it by etiolation and elongating the stem as an avoidance strategy (16). Yan et al. (2010) [4] further confirmed that soybean grown under maize shading in intercropping system has resulted thin stems and easy to lodging. Plant height, first internode length, stem diameter, and dry weight were reported to directly correlate with lodging resistance [18]. However, no lodging incidences were found on these tested varieties in the field. Liu et al. (2017) [17] stated that light quality (than its quantity) had great impact on morphology, as evidenced by the increase in specific leaf area and plant height (internode length) and less branching. Lower light intensity led to less growth, causing smaller final leaf size and stem diameter of soybean in the two intercropping treatments, which resulted in lower yield. Besides shading avoidance, plants usually optimize light captured and utilization under shading, which needed for their high efficiency of carbon gain [13]. Muneer et al. (2004) [19] reported that the light is the main competition factor in which the plant height was negatively affected in intercropping.

Table 1. Performance difference (D) of 16 soybean varieties for morphological and yield components (plant height, stem diameter, no. pod/plant, no of seed/pod, no. seed/plant, 100-seed weight and seed weight/plant) between intercropping and monoculture systems

| Varieties     | Plant height (%) | Stem diameter (%) | No. pod/plant (%) | No. seed/pod (%) | No. seed/plant (%) | 100-seed weight (%) | Seed weight/plant (%) |
|---------------|------------------|-------------------|-------------------|------------------|--------------------|----------------------|------------------------|
| Pangrango     | -1.38            | 5.32              | 5.41              | -17.44           | -19.29             | 3.93                 | -25.28                 |
| Anjasmoro     | 1.98             | -0.83             | -1.38             | -4.60            | -11.53             | -0.58                | -30.24                 |
| Dena 1        | -1.40            | 2.53              | 14.08             | -18.14           | 6.35               | -4.66                | -5.06                  |
| Dena 2        | -9.51            | -5.90             | 21.84             | -29.26           | -5.79              | -0.95                | -18.34                 |
| Wilis         | 1.33             | -14.83            | -27.14            | -3.31            | -28.88             | 1.13                 | -31.52                 |
| Grobogan      | -10.16           | 1.84              | 38.05             | -50.07           | 3.78               | -9.21                | 52.80                  |
| Dega 1        | -13.43           | 7.59              | 1.93              | -1.42            | -0.45              | -9.32                | -18.82                 |
| Demas 1       | -9.36            | 0.84              | 2.24              | -15.49           | -22.38             | -7.42                | -29.91                 |
| Deja 1        | 0.68             | -15.75            | 4.10              | -8.53            | -6.88              | 4.36                 | -43.34                 |
| Devon 1       | -1.77            | 9.80              | 21.63             | -10.53           | 6.60               | -0.65                | 1.91                   |
| Devon 2       | -9.09            | -9.14             | 13.20             | 11.18            | 24.14              | -8.95                | 31.17                  |
3.2. Yield Parameters

When two cropping systems were compared, it observed that there were range of increasing and decreasing yield parameters in each soybean varieties. The decreasing seed weight (-0.72 to -42.06%) was lower than those of [14] whose reported a higher decrement for up to -23.00 to -42.42%. Across the calculated performance difference on yield parameters, Slamet revealed the most decreasing performance (Table 1) (number of pod per plant: -23.89%, number of seed/plant: -36.00%, and seed weight/plant: -42.06%) from monoculture compared to intercropping. Especially Derap 1 showed highest increased on the number of pod/plant (59.07%) and number of seed/plant (18.09%) in intercropping. Intercropping increased seed weight/plant in some soybean varieties tested i.e. Grobogan (52.80%), Devon 1 (1.91%), Devon 2 (31.17%), Derap 1 (13.25%) dan Gepak Kuning (46.12%). Seed weight per plant in Grobogan dan Gepak Kuning were higher in intercropping compared to that of in monoculture. These varieties showed low yield compared to the average of all varieties tested (Figure 1). Dena 1 and Devon 2 gave better seed weight per plant in intercropping. On the other hand, Derap 1 gave the highest seed weight per plant in both cropping system. It argued that this high yield in Derap 1 might be due to the capability of the variety on optimizing the photosynthetic yields to be distributed mainly to the seed rather than to other vegetative organs, such as pods development, stem growth, plant height, and productive branches. As the results, Slamet was assigned as group varieties with low capacities to compete with maize on microclimates and other growth factors. In addition, Grobogan, Devon 1, Devon 2, Derap 1 and Gepak Kuning were assigned as group varieties with high capacities to compete with maize on microclimates and other growth factors. This in turn, showed that there was a different level of tolerance to compete with maize for light, nutrition, and water [21] as plant response on competition for light and water can be an additive, synergic and antagonist [22]. Liu et al. (2019)[23] stated that the maize when intercropped with faba bean produced exudate which lead to root formation, increase root nodules and assist the Nitrogen fixation on faba bean, With the better supply of nitrogen, it showed that both crops can utilize it efficiently. On the contrary, Pangrango, Deja 1, Detap 1 and Slamet suffered a declining seed weight per plant on intercropping. This was in line with the report of Balitkabi (2015) [24], mentioned that Pangrango, Kipas Putih and Slamet had lower yield potential compared to Wilis. This result implied that these 4 varieties were unable to survive and complete their life cycle when intercropped with maize. The lack of sunlight, nutrients, and competition for water were the reasons of this low performance. Other varieties, however, showed a stable but low performance. We also confirmed that Dena 1 was categorized as shading tolerant which was in line with the previous report [24], which reported the similar results.
In each of intercropping and monoculture, the correlation of seed weight per plant and number of pod per plant was significantly and positively correlated (r= 0.56; P=0.024 and r= 0.56; P= 0.022, respectively). The correlation of this parameter to number of seed per plant also showed same trend (r= 0.67 P= 0.004 and r= 0.79; P= 0.000). Number of pod per plant and seed per plant therefore gave a significant impact on seed weight/plant. This result showed that the greater number of pod and seed/plant would increase seed weight per plant in both cropping system. As for its correlation to the other parameters, even though positive, the level was not significant except for the number of branches on monoculture (number of seed per pod: r= 0.47; P= 0.069 and r= 0.33; P=0.217; stem diameter: r= 0.29 P= 0.269; and r= 0.46; P= 0.070); number of branches: r= 0.42; P= 0.105 and r= 0.57; P= 0.022). Seed weight per plant was negatively (but not significant) correlated with 100-seeds weight (r= -0.05; P= 0.866 and r= -0.44; P= 0.089) in intercropping and monoculture, respectively. Number of pods produced in intercropping system was positively correlated with all parameters, except for 100 seeds weight. This implied that the increasing 100-seeds weight had suppressed other parameters. These results were similar to [20] which reported the yield of shaded soybean was positively correlated to seed weight per plant, number of branches (r= 0.34), number of internodes (r= 0.27), number of contained seed (0.55) and 100 seed weight (r= 0.42). Plant height between two cropping systems had correlated differently to seed weight per plant. The decrement of plant height on intercropping was also followed by decrement on seed weight per plant (r = -0.20; P= 0.46). Whereas, the plant height increased on monoculture was also followed by the increment of seed weight per plant (r= 0.28; P= 0.29). These two cropping systems however, showed a negative correlation with 100 seeds weight (r = -0.83).

3.3. Tolerance Selection
To determine the soybean tolerance to intercropping, the performance difference calculation based on seed weight per plant and selection index were employed. The result of selection index based on yield (Ys) in intercropping showed that 7 soybean varieties i.e., Derap 1, Devon 1, Devon 2, Demas 1, Dena 1, Dena 2, and Wilis were grouped as tolerant to intercropping with maize, as their yield were above the average of those 16 varieties in both of monoculture and intercropping (Figure 1).

The 7 varieties belongs to tolerance group were in accordance with its selection indexes results (Table 2). Among 7 selection indexes evaluated, there were 4 selection indexes (STI, MP, GMP and YI), which showed significant correlation coefficient to both of Ys and Yp at 1% and 5%. Among these varieties Derap 1 were the most tolerant variety as it has the highest yield (12.42 g) in intercropping and selection index values for STI (2.15), MP (11.69), GMP (11.67), and YI (1.83), respectively. On the other hand, Dega 1 and Mahameru were categorized as intolerant as its Yp and Ys and 4 selection indexes showed the lowest. The low seed weight per plant on these two varieties showed that the varieties were low yield varieties in both cropping systems. The remaining was grouped as intermediate tolerant in intercropping.

Figure 1. Grouping of 16 soybean varieties based on seed weight/plant (g). Thresholds of averages among all varieties were set as borderline to categorize the varieties into tolerant (above threshold) and intolerant (below threshold) in intercropping and monoculture systems, respectively.
The tolerant varieties indicated that they had less interspecific competition between two species for basic growth resources, which reflected positively on yield attributes of soybean compared with those of its monoculture [5]. The yield increment was supported by other parameters such as number of pods/plant and number of seed produced. The more pod available, more seed weight was expected.

Table 2. Selection indexes of 16 soybean varieties. Pearson correlation coefficient between selection indexes and yields in monoculture and intercropping was depicted on the lower table

| Varieties | Yp | Ys | STI | SSI | TOL | MP | GMP | YSI | YI |
|-----------|----|----|-----|-----|-----|----|-----|-----|----|
| Pangrango | 8.77 | 6.55 | 0.91 | 1.72 | 2.22 | 7.66 | 7.58 | 0.75 | 0.96 |
| Anjasmoro | 6.75 | 4.71 | 0.50 | 2.05 | 2.04 | 5.73 | 5.64 | 0.70 | 0.69 |
| Dena1     | 7.50 | 7.12 | 0.84 | 0.34 | 0.38 | 7.31 | 7.31 | 0.95 | 1.05 |
| Dena2     | 10.74 | 8.77 | 1.48 | 1.24 | 1.97 | 9.76 | 9.71 | 0.82 | 1.29 |
| Wilis     | 10.79 | 7.39 | 1.25 | 2.14 | 3.40 | 9.09 | 8.93 | 0.68 | 1.09 |
| Grobogan  | 4.19 | 6.41 | 0.42 | -3.58 | -2.21 | 5.30 | 5.18 | 1.53 | 0.94 |
| Dega1     | 4.29 | 3.48 | 0.23 | 1.28 | 0.81 | 3.88 | 3.86 | 0.81 | 0.51 |
| Demas1    | 10.69 | 7.49 | 1.26 | 2.03 | 3.20 | 9.09 | 8.95 | 0.70 | 1.10 |
| Deja1     | 10.24 | 5.80 | 0.94 | 2.94 | 4.44 | 8.02 | 7.71 | 0.57 | 0.85 |
| Devon1    | 10.46 | 10.66 | 1.75 | -0.13 | -0.20 | 10.56 | 10.56 | 1.02 | 1.57 |
| Devon2    | 5.20 | 6.82 | 0.56 | -2.12 | -1.62 | 6.01 | 5.95 | 1.31 | 1.00 |
| Detap1    | 8.66 | 5.18 | 0.71 | 2.73 | 3.48 | 6.92 | 6.70 | 0.60 | 0.76 |
| Derap1    | 10.97 | 12.42 | 2.15 | -0.90 | -1.45 | 11.69 | 11.67 | 1.13 | 1.83 |
| Mahameru  | 3.76 | 3.73 | 0.22 | 0.05 | 0.03 | 3.74 | 3.74 | 0.99 | 0.55 |
| Gepak Kuning | 4.29 | 6.27 | 0.42 | -3.13 | -1.98 | 5.28 | 5.19 | 1.46 | 0.92 |
| Slamet    | 10.22 | 5.92 | 0.95 | 2.85 | 4.30 | 8.07 | 7.78 | 0.58 | 0.87 |
| Average   | 7.97 | 6.79 | 0.91 | 0.59 | 1.17 | 7.38 | 7.28 | 0.91 | 1.00 |

Correlation Coefficient

| Yp | 1 | 0.62* | 0.86** | 0.59* | 0.60* | 0.92** | 0.91** | -0.59* | 0.62* |
|----|---|-------|--------|-------|-------|--------|--------|--------|-------|
| Ys | 1 | 0.92** | -0.22 | -0.26 | 0.88** | 0.89** | 0.22 | 1.00** |

Yp, mean yield in monoculture; Ys, mean yield in intercropping; STI, stress tolerance index; SSI, stress susceptibility index; TOL, tolerance; MP, mean productivity; GMP, geometric mean productivity; YSI, yield stability index, YI, yield index. Italic indicated values above its respective average. * and **, significant at $P=0.05$ and $P=0.01$, respectively.

4. Conclusions

Seven varieties i.e., Derap 1, Devon 1, Devon 2, Demas 1, Dena 1, Dena 2, and Wilis were grouped as tolerant to intercropping with maize. Derap 1 was the most tolerant varieties when intercropped with maize.

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