Selection of high-yield maize hybrid under different cropping systems based on stability and adaptability parameters

1 Introduction

Maize is among the most significant crops in the world. This crop supplied human energy consumption demands by more than 50% in 14 countries [1]. As an important commodity, maize is still experiencing ups and downs in production. Fluctuations in the production of this crop in the current era of modern agriculture occur due to global warming, land conversion from agriculture into industry, and decreasing soil quality [2].

An effort to increase maize production can be accomplished by planting maize hybrid varieties. The best maize hybrids in addition to high productivity are hybrids enriched with protein and carbohydrates and resistant to diseases such as downy mildew [3]. However, the effect of using hybrid varieties continuously can cause high consumption of fertilizers and water. The continued use of hybrids will eventually cause the overuse of chemical fertilizers, which can lead to more damage to soil quality and the environment [4–6]. Therefore, efforts are needed to restore soil quality naturally without stopping the use of hybrid varieties.

Modification of the natural growing environment can be done to reduce the excessive chemical fertilizers [7]. Intercropping is a form of modification of the natural growing environment through a cultivation technique that has been developed from generation to generation in developing countries [8]. Intercropping not only increases crop production but also maintains land fertility, food diversification, nutritional source differentiation, and reduction of crop failure [5,6,9,10]. Intercropping of maize with other crops is an integrated farming system, which prioritizes the concept of modification of natural cultivation techniques. Intercropping of maize with other crops had been reported by many scientists. Examples are intercropping maize with sweet potatoes [6,11] and intercropping maize with soybean [6].

Simultaneous planting of maize with other crops in the farm will undeniably cause interactions. Interaction
between maize and other crops should be complementary [11]. Intercropping between maize and other crops have to produce an optimal yield for maize as the main crop and the least reduced yield for the nonprimary crops. Therefore, selection of maize that are adaptive for cultivation under an intercropping system is required.

Selection is a critical stage in developing a maize hybrid which is stable and adaptable for intercropping systems. Some statistical method is universally used to analyze stability and adaptability of new varieties. Linear regression [12], ecovalence value [13], steadiness discordance [14], and coefficient from variance [15] have been used to determine stability and adaptability of new varieties. In addition, genotype and genotype × environment (GGE) have been widely used to study stability and adaptability in various plant commodities such as cucumber [16], lentil [17], oat [18], maize [19], maize as a silage [20], sorghum [21], sweet potato [22], wheat [23], and yam bean [24]. However, selection of maize hybrids under intercropping with other crops has not yet been widely studied. The objectives of the research are to (i) select maize hybrids with the best stability and adaptability under intercropping as well as sole-cropping conditions based on parametric, non-parametric, and multivariate analysis, and (ii) test the ideal cropping system to evaluate best maize hybrids suitable for intercropping.

2 Materials and methods

The experiments were conducted at Arjasari, West Java, Indonesia with an ordinate point of 7°00′31.3″ in the south latitude, 107°32′47″ in the east longitude, and an altitude at ±800 m a.s.l. (above sea level) during two different planting seasons. The first planting was during the rainy season from November 2016 up to February 2017, and the second one was during the dry season from August 2017 up to November 2017. Twelve maize hybrids were selected for the experiment. These hybrids were a result of the breeding program of the Plant Breeding Laboratory, UNPAD. The maize hybrid had high yield potentials, enriched in nutrients such as starch and high protein (Table 1). They are also moderately resistant to downy mildew pathogens [3,8].

The experiments were laid in a split plot based on a randomized block design with three replications. The main plot consisted of maize sole-cropping, maize + soybean intercropping, maize + sweet potatoes intercropping, and maize + rice intercropping, whereas subplots were a randomized block design of 12 maize hybrids. In maize sole-cropping, the genetic materials were planted

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Table 1: The maize hybrids materials and their pedigree

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as four row plots, 5 m long, 0.75 m between rows, and 0.25 m spacing within rows. In intercropping, crops were planted in spatial cultivation in which two rows of maize alternated with two rows of the designated crops, i.e., two rows of maize alternated with soybean for maize + soybean intercropping, two rows of maize alternated with sweet potato for maize + sweet potato intercropping, and two rows of maize alternated with rice for maize + rice intercropping. Soybean and sweet potato were planted two weeks before planting maize. The rows were 5 m long and 3 m width, with planting space 0.75 m between rows and 0.25 m spacing within rows. Population density of the maize in sole-cropping was 66,667 plant ha$^{-1}$, whereas in intercropping was 33,333 plant ha$^{-1}$.

The character observed was yield (t ha$^{-1}$). Yield was measured following Munawar et al. [25], which was modified for sole-cropping and intercropping. Cobs were separately harvested from two rows at maturity and the fresh cob was weighted for every plot. Grains were shelled from 10 randomly cobs to estimate the percent grain moisture and shelling% at harvest for every plot. The shelling% was calculated using formula:

\[
\text{Shelling percentage (SP) = \frac{\text{Grain weight}}{\text{Cob weight} \times 100}}.
\]

(1)

Yield (t ha$^{-1}$) was estimated from fresh cob per plot using formula:

\[
\text{Yield} = \frac{y \times (100 - \text{MC}) \times \text{SP} \times 10}{100 - 15 \times 7.5},
\]

(2)

where MC = moisture content in grains at harvest (%); SP = shelling percentage; area harvested plot = 7.5 m$^2$; 1 hectare = 10,000 m$^2$; 15% = MC required in maize grains at storage.

Analysis of variance (ANOVA) for the yield was calculated following Gomez and Gomez [26]. Homogeneity of variance errors for four cropping systems under two different seasons was calculated by the Barlett test [26]. Combined ANOVA of all cropping systems were done to estimate the $G \times E$ interaction if variance errors were homogenous.

Superior maize hybrids were selected based on numerical, i.e., parametric and non-parametric stability and graphical GGE biplot analysis. Parametric stability was estimated based on the linear regression coefficient ($b_i$) [12], mean variance component ($\theta_0$) [13], the hybrid $\times$ environment (GE) variance component ($\theta_{ij}$) Nassar and Huehn [27], Wricke’s ecovalence ($W_i^2$) [13], Shukla’s stability variance ($\sigma^2_i$) [14], and coefficient of variance (CV$_i$) [15]. Nonparametric stability included $S_n$, NP, and KR. Graphical analysis was estimated based on the GGE biplot.

Linear regression was estimated by the formula of Eberhart and Russel [12], when the coefficient $b_i$ is equal to 1 and deviation variance ($S^2_{di}$) is equal to zero then the maize(s) were classified as stable. The mean variance component ($\theta_0$) was calculated by Plaisted and Peterson [28]:

\[
\theta_0 = \frac{p}{(2p-1)(q-1)} \sum_{j=1}^{q} \left(x_{ij} - \bar{X}_i + \bar{X}_j \right)^2 + \frac{\text{GE sum of squares}}{2(p-2)(q-1)}.
\]

(3)

The GE variance component ($\theta_{ij}$) was estimated according to the formula [27]:

\[
\theta_{ij} = \frac{p}{(2p-1)(q-2)(q-1)} \sum_{j=1}^{q} \left(x_{ij} - \bar{X}_i - \bar{X}_j + \bar{X}_s \right)^2 + \frac{\text{SSGE}}{(p-2)(q-1)}.
\]

Wricke’s ecovalence ($W_i^2$) [13] was computed by the formula:

\[
W_i^2 = \sum (X_{ij} - \bar{X}_i - \bar{X}_j + \bar{X}_s)^2.
\]

(5)

Shukla’s stability variance ($\sigma^2_i$) [14] was calculated by the formula:

\[
\sigma_i^2 = \left| \frac{p}{(2p-1)(q-1)} \right| W_i^2 - \frac{\sum W_i^2}{(p-1)(q-2)(q-1)}.
\]

(6)

CV$_i$ [15] was evaluated following formula:

\[
\text{CV}_i = \frac{\text{SD}_i}{X_i} \times 100,
\]

(7)

where $x_{ij}$ = yield of genotype $i$ in location $j$; $\bar{X}_i$ = yield of genotype $i$; $\bar{X}_j$ = average yield of location $j$; $\bar{X}_s$ = average overall yield; $p$ and $q$ = the number of genotypes and environments, respectively; and SD$_i$ = standard deviation of a genotype mean across locations.

Nonparametric stabilities were estimated by the formula of Nassar and Huehn [27], Huehn [29], Thennarasu [30], and Kang [31]. Nonparametric stability of Nassar and Huehn [27] and Huehn [29] followed these formula:

\[
S_{ij}^{(1)} = 2 \sum_{j=1}^{n} \frac{\sum_{j=1}^{n} |r_{ij} - r_{ij}'|}{N(n-1)}, \quad S_{ij}^{(2)} = \frac{\sum_{j=1}^{n} (r_{ij} - \bar{r}_i)^2}{N(n-1)}, \quad S_{ij}^{(3)} = \frac{\sum_{j=1}^{n} (r_{ij} - \bar{r}_j)}{\bar{r}_i}.
\]

(8)

where $r_{ij}$ = rank of genotype $i$ in environment $j$; $\bar{r}_i$ = rank of mean of genotype in all environment; $N$ = total environment.

Stability of NP$^{(i)}$ was calculated by the formula of Thennarasu [30]:
NP(2) = \frac{\left[\sum_{j=1}^{n} r_{ij} - M_{dil} / M_{di}\right]}{N},
NP(3) = \frac{\sum_{i=1}^{N} (\bar{r}_i - \bar{y})^2}{\bar{r}_i},
(9)

where \( r_{ij} \) = rank of genotype \( i \) in environment \( j \) based on adjusted data; \( M_{di} \) = rank of mean of genotype based on adjusted data; \( M_{dil} \) = parameter that estimated based on unadjusted data. \( N \) = total environment.

Rank stability of KR was computed by Kang [31], wherein yield and stability variance of the genotype with a high yield and stability is weighed 1. Software STABILITYSOFT [32] was used to compute yield stability based on parametric and nonparametric methods.

The GGE biplot was suggested by Yan et al. [33] to select a high-yield variety that is stable and adaptable to multi-environment conditions. The GGE biplot model was formulated as the following [33]:

\[ Y_{hi} = \mu + E_h + G_i + GE_{hi} + B_{jhi} + e_{hij}, \]

where \( \mu \) = population mean; \( E_h \) = environmental effect; \( G_i \) = genotypic effect; \( GE_{hi} \) = genotypic × environment effect; \( B_{jhi} \) = block effect; and \( e_{hij} \) = random error. The GGE biplot was composed of the general mean and interaction principal component axes score. STABILITYSOFT was also used to estimate combined ANOVA, GGE, and to form their biplots [32].

### 3 Results

ANOVA of yield for different cropping systems is presented in Table 2. The ANOVA revealed significant variations among the hybrids for yield. Significant mean squares of yield for sole-cropping, intercropping, and for all environments are presented in Table 2. This is due to environment (E), hybrid (G), and GE.

Nonparametric and parametric stability for yield is shown in Table 3. It is shown that maize hybrid MDR 9 1.3 × MDR 11.3, G4, with \( b = 1.145 \), and hybrid DR 8 × MDR 18 8.1, G10, with \( b = 1.18 \) have slopes closer to 1.00 than the other 10 hybrids. In addition, these hybrids contributed the least \( G \times E \) interaction as calculated by Wricke’s eovc (\( W_{ij}^2 \)) [13] and Shukla’s stability variance (\( a_i^2 \)) [14]. Thus, these two hybrids have smaller deviation than the rest of the hybrids from regression on site index, as indicated by the deviation mean square of \( s^2d_i \), of all hybrids for yield.

Stability estimation of maize hybrids based on non-parametric \( S(i) \), \( NP(i) \), and KR for rainy and dry seasons are shown in Table 3. Maize hybrids G1, G4, G10, and G12 were the most stable hybrids over four cropping systems and two season tests. They have the smallest values among the 12 maize hybrids based on stability parameters of \( S(i) \), \( NP(i) \), and KR.

The “which–won–where” GGE biplots for yield of 12 hybrids are presented in Figure 1. The values of the first principal component (PC1) and the PC2 were estimated to generate a GGE biplot graph. The biplot graph assisted in finding the best-performing genotypes adapted at each environment or the stable genotype for all environment and even determined the most representative environment (mega-environment) for a genotype [20,34,35]. Figure 1 shows which maize hybrids won in either a sole-cropping or intercropping with nonprimary crops (soybean, sweet potato, and rice). The vertex hybrids for every region of the biplot showed the high-yielding hybrid in the season, which dropped in that region. Hybrids positioned near the base of the biplot were steadier than the top high-yielding hybrids. Hybrids, which shaped the curves of the biplot in the sole-cropping (G1, G2, and G10) and intercropping (G9, G5) trials, include

### Table 2: Combined ANOVA and statistic parameters for yield of maize hybrids under different cropping systems and planting seasons

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<td>CV (%)</td>
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**Significant at the level of 1%; MS – mean square; df – degree of freedom; CV – coefficient of variance.
Table 3: Parametric and nonparametric stability parameter of maize hybrids across rainy season 2016 and dry season 2017

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<th>S⁽³⁾</th>
<th>S⁽⁶⁾</th>
<th>NP⁽¹⁾</th>
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the most sensitive hybrids to planting seasons in their particular ways associated to the other hybrids. The line which begins from the base of the biplot and distributes vertically toward the ends of the biplot grouped the polygon into distinctive regions. For sole-cropping, G11 and G2 were the top-yielding hybrids for maize sole-cropping at rainy season – L1 and G10 was the winner hybrid for maize sole-cropping at dry season – L5. G9 was the top-yielding hybrid for maize + soybean intercropping both in rainy (L2) and dry seasons (L6); thus, this G9 was the winner hybrid for maize + sweet potato (L3) and maize + rice intercropping (L4) in rainy season. In addition, G5 was the top-yielding hybrid for maize + sweet potato (L7) and maize + rice (L8) intercropping in dry season. However, no environments fell in the region with G3 and G2 as vertex hybrids (Figure 1).

The GGE biplot viewing position of hybrids comparative to an ideal genotype for the following cropping systems for rainy and dry seasons. L1 – sole-cropping in rainy season, L2 – maize + soybean in rainy season, L3 – maize + sweet potato in rainy season, L4 – maize + rice in rainy season, L5 – sole-cropping in dry season, L6 – maize + soybean in dry season, L7 – maize + sweet potato in dry season, and L8 – maize + rice in dry season.

Figure 1: The “which–won–where” graph of the genotypic main effects plus GGE biplot for maize hybrids tested under different cropping systems for rainy and dry seasons. Code of genotypes are given in Table 1. PC – principal component. The code of environments: L1 – sole-cropping in rainy season, L2 – maize + soybean in rainy season, L3 – maize + sweet potato in rainy season, L4 – maize + rice in rainy season, L5 – sole-cropping in dry season, L6 – maize + soybean in dry season, L7 – maize + sweet potato in dry season, and L8 – maize + rice in dry season.

Figure 2: The GGE biplot viewing position of maize hybrids compared to an ideal genotype for the following cropping systems for rainy and dry seasons. PC – principal component. The code of environments: L1 – sole-cropping in rainy season, L2 – maize + soybean in rainy season, L3 – maize + sweet potato in rainy season, L4 – maize + rice in rainy season, L5 – sole-cropping in dry season, L6 – maize + soybean in dry season, L7 – maize + sweet potato in dry season, and L8 – maize + rice in dry season.

are more representative of all environments than those making great angles. The average environment and an ideal hybrid is described by the maximum vector size and small G × E and is symbolized by the bold diamond (Figure 2), suggesting its highest mean yield and stability. G9 and G10 were the ideal hybrids for cultivating under different cropping systems in this study (Figure 2).

The vector view of the biplot is presented in Figure 3. This graph describe the connections between the environments and the biplot source over the vectors. Negative association (>90°) was detected between maize sole-cropping during rainy season (L1) and all intercropping systems including L1 and L2, L1 and L3, L1 and L4, L1 and L6, L1 and L7, and L1 and L8. On the other hand, positive association (<90°) was detected between maize sole-cropping system during rainy season (L1) and dry season (L5), maize sole-cropping during dry season (L5) with all intercropping systems (L2, L3, L4, L6, L7, and L8), and between intercropping systems (L2 and L3, L2 and L4, L2 and L5, etc.). In Figure 3, the size of the vector estimates the SD within the environment. This vector’s size is also a degree of ability from the environment to categorize the hybrids. Short environment vectors explained that the environment was weakly connected compared to the
environment with long vectors. The short-vector environments (L6, L7, and L8) offered less or no evidence concerning the hybrids compared to environments with long vectors (L1, L2, L3, L4, and L5) (Figure 3).

4 Discussion

All hybrids in this study had different genetic backgrounds including mutant and nonmutant parentals (Table 1). These hybrids had higher yields than commercial check hybrids. This is revealing the potential for developing superior high-yield hybrids over the existing commercial hybrid in Indonesia. The high-yield hybrids which are cultivated under different cropping systems and across planting seasons included inbred lines DR 8, DR 10, DR 18, mutants of MDR 1.1.3, MDR 3.1.4, MDR 7.4.1, MDR 7.1.9, MDR 9.1.3, and MDR 18.8.1 as parental lines. These inbred lines and mutants were used to form potential hybrids in this study including G1, G2, G6, G9, and G10 (Table 3). The use of parental lines selected concurrently in intercropping and sole-cropping provides the advantage of generating high-yielding and intercropping-suited hybrids.

The experiments also confirmed the chance of identifying hybrids that can cultivate well across sole-cropping and intercropping systems; two of five top-yielding hybrids exhibited superior performance under distinctive cropping system conditions.

The change response of hybrids when cultivated under diverse cropping systems and planting seasons (years) indicated the broad genetic potential of maize hybrids resulting in the possibility of determining suitable hybrids under sole-cropping and intercropping systems. Previous researchers stated the existence of important yield variations among hybrids tested for different conditions [34–36]. Significant effects of the environment explained that every cropping systems were unique. Significant interaction of GE results revealed the presence of an interaction and variation in the position of the hybrids across distinct environments. The response of the hybrids is indicated by changed levels of yield decrease could be projected under the intercropping system due to the interaction between maize and its nonprimary crops [7,8]. The interaction between primary and nonprimary crops changed actively in aspects of ecology, physiology, and agronomy of each crop involved in intercropping. This interaction could limit the progress in selecting suitable hybrids with superior performance in various cropping systems. Therefore, an appropriate breeding scheme needs to be formulated to improve stable varieties in various cropping systems or specific adapted varieties [37,38].

G4 and G10 were designated for stable hybrids of the 12 high-yield hybrids across cropping systems and seasons based on parametric stability. Of the two hybrids, G10 was preferred due to its mean yield higher than that of G4. On the other hand, the nonparametric stability criteria revealed that G10 and G12 could be selected for the stable hybrids of the 12 high-yield hybrids across cropping systems and seasons. Based on these criteria of stabilities, G10 showed lowest average rank of stability; therefore, this hybrid was selected as a stable and high-yield maize hybrid.

The GGE biplot “which–won–where” patterns divided the biplot into six different regions (Figure 1). Yan and Tinker [34] explained that there are several high-yield hybrids for those sectors if a diverse test environment existed in this diverse regions. This is designating the presence of crossover interaction between the genotype and environment and proposing of splitting the environments into mega-environments [18,38]. The polygon biplot was divided into two regions for maize sole-cropping, namely environment L1 and L5 (Figure 1), whereas one region that was represented by environment L2 and L6 was observed for intercropping maize and soybean (Figure 1). Furthermore,
two regions represented by environment L3 and L7 were observed for intercropping maize and sweet potato. Thus, two regions that represented by environment L4 and L8 were observed for intercropping maize and rice (Figure 1). Some researchers explain that data are critical in grouping diverse environments into a mega-environment [37–40]. No environment fell in the region where the G3 was the top hybrid. It demonstrated that hybrid was the smallest yielding hybrid for this study. The results of this study specified delimitation of the present data on mega-environments. Extensive research on planting seasons as well as multi-locations are needed to confirm this finding.

Yan and Kang [41] and Mebratu et al. [38] described the best genotype as the topmost yielding and the most stable genotype. In this study, the most suitable hybrids which confined to the ideal genotype were classified under each cropping system suggesting specific adaptation (Figure 2). G10 was classified as an ideal maize genotype under maize sole-cropping and G9 for maize + soybean intercropping both in rainy and dry seasons; thus this G9 was the winner hybrid for maize + sweet potato and maize + rice intercropping in the rainy season, indicating the essential prospective of G9 for a high yield and specific adapted hybrid.

The relationships of the vectors from two environments were as follows: (i) an angle of less than 90° revealed strong association of genotype between these environments; (ii) an exact angle of 90° revealed orthogonality and weak association; and (iii) an angle of more than 90° revealed a negative connection of genotype between these environments [38,42]. As explained by some plant breeders [19,38,40], positive associations revealed connection of genotype among the environments, whereas negative or weak associations demonstrate the strong influence of the genotype-environment interaction (GEI). Furthermore, Yan and Kang [41] suggested if negative associations existed then evaluation of genotypes to improve the gain of selection for high yield are required to be handled separately. Environments with positive associations are considered laid off due to increased trial evaluation expenses. The vector view of the GGE biplot in Figure 3 described positive correlations between different cropping systems in this study suggesting that the selection for high grain yield could be possible conducted in any season.

Yan et al. [18] and Mebratu et al. [38] explained the valuable environment for evaluating cultivars as environments with long vectors and slight angles with the AEC abscissa. In this study the AEC abscissa was equal to AEA, hence L5 and L4 were classified as discriminant environments for the hybrids evaluated under sole-cropping and intercropping. Oyekunle [19] and Mebratu et al. [38] described the ideal environment for the environments which could be used to select superior hybrids and to identify adaptive varieties for a specific environment. Furthermore, some researchers explained that testing under discriminant conditions in the early stage will reduce the variety improvement cost by cutting the number of varieties to be selected and reducing the number of locations/seasons [19,21,38,43].

5 Conclusion

The stable maize hybrids as well as adapted maize hybrids for sole-cropping and intercropping systems were determined in this study. Based on parametric and nonparametric stability, G10 was identified as a low average stability value but produced high yields for all cropping systems. Based on GGE biplots, the adapted maize hybrids for the specific cropping system in this study were G10 for maize sole-cropping and G9 for maize intercropping. The L5 and L4 were ideal and discriminant environments for evaluating hybrids under different cropping systems. The adapted hybrids detected in this study should be broadly evaluated on-farm in order to disseminate for small-holder farmers in Indonesia.

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References

Selection of high-yield maize hybrid under different cropping systems


