Development of high yielding sugarcane varieties for rainfed areas: yield multilocation trial of promising sugarcane clones

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Abstract. Two promising new sugarcane clones PS 05-370 and PS 06-103 along with control varieties were evaluated for the stability of their performance at ten locations across three years. Parameters observed include cane yield in tonnes cane per hectare (TCH), sugar content or commercial cane sugar (CCS) in %, and sugar yield in tonnes sugar per hectare (TSH). Significant differences were observed in genotypes and locations x genotypes interactions for TCH, CCS and TSH. Additive Main Effect Multiplicative Interaction (AMMI) stability analysis showed that these two sugarcane clones are specific location; grown in inceptisol soil with C3 climate type (Oldeman), sugar productivity (TSH) of PS 05-370 and PS 06-103 increased by 17-21%, compared to standard control variety PS 881. These two promising clones are early to mid maturing varieties and therefore, are recommended to be harvested earlier, to fill up the need for crushed material in the beginning of the milling season.

Keywords: specific, adaptation, early-mid maturing, HYV, sugarcane

1. Introduction
Sugarcane is one of the world’s important industrial commodities, because in addition to producing sugar, it also produces a variety of industrial raw materials, such as biofuel (ethanol), amino acids, organic acids and foodstuffs (e.g., mushrooms) [3,21]. In the 1930s, Indonesia was once the largest sugar exporter in the world, but now Indonesia is one of the world’s largest importers [28-29], with a value of around US $ 900 million or equivalent to 2 million tons sugar every year [1]. The reason is, in addition to increasing domestic sugar consumption, also due to less supportive agricultural policies, increasing conversion of agricultural land in Java, the transition of sugarcane cultivation from rice fields to dry and marginal land, due to intense competition with food crops, and the decline in sugarcane productivity and low yield [18].

Development of sugarcane on dry land experiences obstacles due to drought stress. Drought stress is reported to significantly affect the growth of sugarcane and can reduce production by up to 70% [6, 21]. Hybridization program to develop high yielding and drought resistant cane varieties has been started since 2004. The crosses between proven parents and donor parents produced 330 potential clones. Subsequent evaluation, from 2011 to 2017, selected 16 promising sugarcane clones with high...
productivity and sugar yield in rainfed dry land [9-13]. Of these, two are promising clones with consistently showing high productivity and sugar yield in a few locations.

Adaptability and stability of these promising clones need to be assessed in depth due to the following reasons. Stability analysis characterizes the performance of a genotype in various environments while helping breeders to choose promising genotypes. Information on the stability and adaptability of a prospective variety becomes very important because the variety will be planted by farmers in different environments so that stable varieties are needed to provide high yields and are adaptive to cross environmental conditions. Parametric statistical methods are widely used in plant breeding to estimate the phenotypic stability of a genotype. Researchers has identified three different concepts of stability [17]. The first concept, a genotype is considered stable if the diversity between environments is small. It is known as static or biological stability [2, 25] The parameters used to describe this type of stability are the coefficient of diversity (CVi) and cross-environment genotype variants (Si 2) and the determinant coefficient (r2) [7]. The concept of stability is useful for qualitative characters, disease resistance or environmental stress. The second concept, genotypes are considered stable if the results in an environment are equivalent to the average yield of all genotypes in that environment, called dynamic or agronomic stability [2]. The stability parameters used in dynamic stability are regression coefficients or $\beta_i$ [5], ecovalece or $W_i 2$ [12] and stability variability or $\sigma i 2$ [14]. The third concept states that a genotype is stable if the Error Mean square of the regression model environmental index is low. The environmental index is the average yield of all genotypes in each environment minus the total average of all genotypes in all locations. This type also includes dynamic stability. This type of stability parameter is displayed through the regression deviation or $\delta i 2$ [4, 23]. Several methods to explain and interpret genotype responses to environmental variations have been developed. This method is used to determine the size of the genotype x environment interaction and its effect on the stability of the results. Regression analysis is one method that is often used. The first regression method [5] and was later modified [4] determine the adaptability and stability of a genotype, parameters such as average yield, regression coefficient ($\beta_i$) and deviation from regression ($\delta i 2$) are used. According to Finlay and Wilkinson [5], ideal varieties are those that have maximum yield potential in the most productive environments and have maximum stability. Stable varieties are those that have a regression coefficient ($\beta_i$) equal to one and a regression deviation ($\delta i 2$) equal to zero. According to Eberhart and Russel [4], a genotype with high yields and fulfilling both of the above criteria will have a good performance in all environments. The above method is quite effective for sorting stable and specific genotypes. However, the above approach still leaves a large variability interaction. This happens because this approach only explains the linear component of the interaction effect so that if the pattern of genotype interactions on the environment is not linear, it will leave considerable diversity [27]. In its development, the results stability analysis is expected to explain the influence of genotype x environment interactions in more detail. In 1988, Gauch and Zobel introduced the "Additive Main Effect Multiplicative Interaction" (AMMI) method [27].

This paper reports the results of yield multilocation trials, including AMMI stability analysis of these two promising clones.

2. Material and Methods

The yield of two promising clones was tested in four dryland locations, three in Java and one in South Sulawesi. The climate type and soil type of the test site, respectively, followed the Oldeman [22] and US soil taxonomy [30] classification, as listed in Table 1.

Multilocation tests were performed on the plant cane (PC) and first ratoon cane (RC-1), with a randomized block design that was repeated three times. Each plot consists of 5 rows @ 10 meters and the interplots are separated by one dead row. Each pot in a pot is planted with 20 sets two eyes in each location. The multilocation test followed the observation procedures for growth components, responses to natural attacks from pests and diseases, a standard industry measurement for sugar content known as commercial cane sugar (CCS) analysis, harvest and weighing sugarcane according to the standard experiment guidelines for sugarcane screening [13]. The control varieties used are commercial varieties.
that are widely developed in each test location, i.e. PS 881 or Kenthung. The dosage of fertilizer given was 300 kg N + 60 kg P₂O₅ + 60 kg of K₂O per ha is equivalent to 600 kg of ZA + 400 kg of NPK compound per ha. Stem borer were controlled with an active insecticide monocrotophos, or asefat at a dose of 3 L/ha. Parameter observed include cane yield in tonnes per hectare (TCH), Commercial cane sugar (CCS) in % and sugar yield on tonnes sugar per hectare (TSH) [20]. Data collected were analyzed using Analysis of variance (Anova) [8, 15].

Table 1. Climate and soil types of the multilocation trial across years and locations

| Climate type (Oldeman) | Soil type          | Year     | Location/coordinates          |
|------------------------|--------------------|----------|-------------------------------|
| D2                     | Alfisol            | 2015-2017| Pati (rainfed) 6°43’26.508” S/110°59’36.377” E |
| C3                     | Inceptisol (regosol)| 2014-2017| Kediri (rainfed) 7°53’5.539” S/120°10’21.029” E |
| C2                     | Inceptisol         | 2016-2017| Bone (rainfed) 4°51’28.188”S/120°5’15.5”E |
| C3                     | Inceptisol         | 2015     | Malang (rainfed) 7°54’34.47”S/112°37’21.842”E |

3. Results and discussion

3.1. Yield performances of the two promising clones
Based on the results of testing in 10 experimental units, the two promising clones PS 05-370 and PS 06-103 showed a real advantage compared to the standard varieties (PS 881 or Kenthung). PS 05-370, a progeny of the cross between PS 951 as female parent with IRK 67-1 as male parent, suitable to be developed on land with soil type inceptisol (regosol). Of the 10 testing units in four different locations, PS 05-370 excelled at the location of inceptisol (regosol) C3, and inceptisol C3 Bone. The sugar productivity increased 17% to 30% compared to standard PS 881 variety (Table 3). While PS06-103, a polycross progeny with VMC 87-599 as the female parent, suitable to be developed on the land with soil type inceptisol regosol (C3), inceptisol B and inceptisol regosol. The sugar productivity increased upto 52% in inceptisol (regosol) C3 (Table 4).

3.2. Stability test
AMMI analysis is a combination of the influence of additives on the analysis of variance and the multiplicative effect on the analysis of the main components. Decomposition of the interaction effect is carried out with the bilinear model, so that the suitability of the growing site for the genotype can be clearly mapped. Clearly seen in the mapping of genotypes and the environment simultaneously using biplots [27]. Thus, the use of AMMI analysis for the evaluation of the stability of sugarcane clones is expected to increase the accuracy of the alleged response of clone interactions with the environment.

Before the AMMI test is carried out, the cane yield (TCH), commercial cane sugar (CCS) and sugar yield (TSH) data of sugarcane clones are checked against the 3 assumptions that must be fulfilled in the AMMI test, which are random assumptions, normality and homogeneity. If one of the assumptions is not fulfilled, an appropriate transformation is carried out. The results of the combined analysis of the two promising clones and their comparative varieties are presented in Table 2. It can be seen that the genotypes and locations have a very significant effect on the cane yield, CCS and sugar yield of the promising clones tested. Whereas the interaction of genotypes with environment was significant for cane yield and sugar yield, and were not significant for CCS parameters. This shows that CCS of sugarcane
clones is not influenced by the growth environment. Similar results were reported by researchers from Australia [13].

**Table 2.** Pooled analysis of the promising clones across ten locations

| Source of variability | Df | Cane yield (ton/ha) | CCS/rendemen (%) | Sugar yield (ton/ha) |
|-----------------------|----|---------------------|------------------|---------------------|
| Location (L)          | 9  | 0.267033 ***        | 11.9991 ***      | 41.940 ***         |
| Genotype (G)          | 2  | 0.076283 ***        | 1.7624 *         | 5.328 *            |
| Replication           | 2  | 0.051729 **         | 1.9283 **        | 16.291 ***         |
| LxG                   | 18 | 0.065560 ***        | 0.6230 ns        | 6.959 ***          |
| Error                 | 58 | 0.0079              | 0.3702           | 1.359              |

Notes: *, **, ***: significant at 5%, 1% and 0.1% level, respectively. Ns=not significantly different

IAKU2 biplot is a visualization tool from AMMI analysis that can be used to see genotypes that are stable in all test locations or site-specific at a particular location. **Figure 1** shows a biplot between KU1 and KU2. The line that connects the clone to the centre (0,0) shows the close relationship between genotype and environment, where the shorter the line that connects the genotype to the centre, the higher the stability of the genotype [19]. From the picture it can be seen that the promising clones PS 05-370 and PS 06-103 are classified as unstable. PS 06-103 promising clones are very suitable to be developed in locations with land echolocation of Inceptisol C3, Inceptisol (Regosol) C3 and Inceptisol C3. Whereas promising clones PS 05-370 are suitable to be developed in echolocation of inceptisol (regosol) C3 and inceptisol C3.

**Figure 1.** Diagram biplot for cane and sugar yields. PS06-103, 2. PS05-370, 3. PS.881. 1. Inceptisol C3, 2. Inceptisol (Regosol) C3, 3. Inceptisol (Regosol) C3, 4. Alfisol D2, 5.Inceptisol (Regosol) C3, 6. Inceptisol C3, 7. Alfisol D2, 8. Inceptisol (Regosol) C3, 9. Inceptisol D2, 10. Alfisol D2
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### Table 3. Yield performances of PS 05-370 in each location and the corresponding estimation of NMG

| No | No of testing units | Specific location | Category | Clones/variety | Cane yield (TCH) | CCS | Sugar yield (TSH) |
|----|---------------------|-------------------|----------|----------------|------------------|-----|------------------|
|    |                     |                   |          |                | Average (t/ha)   | NMG | Average (%)      | NMG | Average (t/ha)   | NMG |
| 1  | 4                   | Inceptisol (regosol) | PC       | PS05-370       | 11.45            | 1.19 | 8.5              | 1.0  | 9.05            | 1.27 |
|    |                     |                   |          |                | 12.0             | 1.20 | 7.5              | 1.0  | 8.90            | 1.17 |
|    |                     |                   |          |                | 10.0             | 1.0  | 7.5              | 1.0  | 8.90            | 1.17 |
| 2  | 3                   | Alfisol C Pati    | PC       | PS05-370       | 14.6             | 0.91 | 8.2              | 0.98 | 11.75           | 0.89 |
|    |                     |                   |          |                | 13.1             | 1.54 | 8.8              | 0.88 | 11.5            | 1.29 |
|    |                     |                   |          |                | 8.5              | 1.0  | 10.0             | 1.0  | 9.7             | -    |
| 3  | 1                   | Inceptisol B Malang | PC       | PS05-370       | 9.98             | 1.06 | 9.8              | 0.92 | 9.6             | 0.96 |
|    |                     |                   |          |                | 9.4              | 1.06 | 10.6             | 1.0  | 10.2            | -    |
| 4  | 2                   | Inceptisol C Bone | PC       | PS05-370       | 10.1             | 1.04 | 7.9              | 1.12 | 8.0             | 1.17 |
|    |                     |                   |          |                | 9.7              | 0.7  | 7.0              | 1.12 | 8.0             | 1.17 |
|    |                     |                   |          |                | 12.5             | 1.27 | 10.6             | 1.06 | 13.3            | 1.30 |
|    |                     |                   |          |                | 9.8              | 1.0  | 10.0             | 1.0  | 10.2            | -    |

Note: NMG = net merit grade

### Table 4. Yield performances of PS 06-103 promising clone in each location and the corresponding estimation of NMG

| No | Number of testing units | Specific location | Category | Clones/variety | Cane yield (TCH) | CCS | Sugar yield (TSH) |
|----|-------------------------|--------------------|----------|----------------|------------------|-----|------------------|
|    |                         |                    |          |                | Average (t/ha)   | NMG | Average (%)      | NMG | Average (t/ha)   | NMG |
| 1  | 4                       | Inceptisol (regosol) | PC       | PS06-103       | 12.7             | 1.32 | 8.7              | 1.02 | 10.8            | 1.52 |
|    |                         |                   |          |                | 12.5             | 1.20 | 7.2              | 1.0  | 8.90            | 1.17 |
|    |                         |                   |          |                | 10.0             | 1.15 | 7.5              | 1.0  | 7.60            | -    |
| 2  | 3                       | Alfisol C Pati    | PC       | PS06-103       | 12.1             | 0.76 | 8.75             | 1.05 | 10.6            | 0.80 |
|    |                         |                   |          |                | 11.7             | 0.7  | 9.8              | 0.88 | 11.8            | 0.96 |
|    |                         |                   |          |                | 8.5              | 1.0  | 10.0             | 1.0  | 8.9             | -    |
| 3  | 1                       | Inceptisol B Malang | PC       | PS06-103       | 11.0             | 1.17 | 10.3             | 0.97 | 11.5            | 1.15 |
|    |                         |                   |          |                | 9.4              | 1.17 | 10.6             | 1.11 | 10.0            | -    |
| 4  | 2                       | Inceptisol C Bone | PC       | PS06-103       | 11.4             | 1.17 | 7.8              | 1.11 | 8.9             | 1.30 |
|    |                         |                   |          |                | 9.7              | 0.98 | 10.9             | 1.09 | 10.5            | 1.03 |

Note: NMG = net merit grade

### 4. Conclusion

The two promising clones (PS 05-370 and PS 06-103) proved to be promising compared to the standard check varieties; their sugar productivity increased by 17% to 30%. Being an early maturing type, these two promising clones can fill the balance of arrangement of varieties at the beginning of the milling season which has been very limited. Before being released as a new variety, the resistance level of the promising clones need to be assessed properly [16, 26] notably, their resistant to main pest and diseases and analysis of farming.

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