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Stress tolerance indexes of Maize (*Zea mays L.*) grown in the southwestern savannah in the Democratic Republic of Congo

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ABSTRACT: Twenty maize varieties were evaluated in southwestern savannah of DR. Congo during two years for their grain yield potential under optimum and water deficit conditions. A factorial experimental design with three replicates was adopted. Grain yield obtained under optimum was considered as yield potential (Ri) while the one in water deficit conditions was considered as yield performance under stress (Rs). Six stress tolerance indexes, including Stress Tolerance Index (STI), the Sensitivity to Stress Index (SSI), mean productivity (MP), geometric mean productivity (MGP), the stability index Performance (ISR) and stress tolerance (TOL) were used to identify genotypes tolerant to drought. Linear regressions were done between Ri and Rs yields and between six stress tolerance indexes. High positive correlations were revealed between Ri and Rs yields and indexes STI, MP and MGP. Furthermore SSI and TOL indexes were highly correlated positively and negatively to SRI at Rs. High significant correlations were observed between STI, MP and MGP while SRI, SSI and TOL are highly correlated, and are slightly or not correlated with STI MP and MGP. Varieties ranking based on STI, MP and MGP is similar to that based on the combination of the two rankings prepared on Ri and Rs. For maize, ranking varieties based on SSI and TOL is in the opposite direction of that obtained according to the Ri and Rs yields. The selection of lines based on the index can be more effective by combining high values of STI and MP at low to moderate values of SSI and TOL.

KEYWORDS: Maize, INERA, DRC, stress index, SSI.

1 INTRODUCTION

The water deficit is the major problem that seriously affects the production and quality of cereals in savannah conditions. Several strategies including changes in agricultural practices and the choice of cultivars more tolerant to drought have been adopted to solve this problem [1].

Studies were conducted under stress and non-stress conditions to describe the stability and elasticity of a cultivar under growing conditions with or without water stress [2], as well as approaches to estimate the impact of climate variability on yield [3] and the development of efficient methods of using water [4].

Research has been undertaken since the early 80s, in order to correlate the variations in yields, the interactions with the crop environmental conditions to stress tolerance index. These indices are based on the loss of performance under water deficit compared with normal [5].

The results from several previous investigations showed that the genotypes and environments interaction (G x E) are partially due to stress tolerance indexes [6]. Indeed, the difference between yield potential under optimum and yield deficit under stress, could enable classifying the varieties based on their level of drought tolerance. These indexes provide a measure of limitation and an adequate way of identifying stress-tolerant genotypes [7].

The objective of this study is to assess the reaction of some cultivars to water stress and determine the best index to increase and improve yields under stress and non-stress conditions of DRC south western savannahs.

2 MATERIALS AND METHODS

The study was conducted in Mvuazi Research Center of the National Institute for Agronomic Study and Research (INERA). The plant material consists of a total of twenty maize varieties including twelve obtained from CIMMYT/ IITA and eight grown in the south western savannah of DR Congo (Table1).

The trial was carried out during two years (2013 and 2014). The first planting was done during the long rainy season (mid-October to February) and the second one during the short rainy season (mid-March to June).

Urea (46% nitrogen) and NPK 17-17-17 bought on the local market were used as fertilizers. NPK (250 kg.ha-1) was applied at planting as basal dressing. Urea (120 kg) was applied by fractionation into two halves of the dose at 15 days and 30 days after sowing.

The planting time under water deficit conditions was chosen in such a way to match the flowering period and the breaking rains.

Table1. Origin and types of maize varieties tested for stress tolerance index during 2013 and 2014 in Mvuazi

Varieties	Origine	Type
07SADVE	CIMMYT	Normal
08SADVE1	CIMMYT	Normal
09SADVE-F2	CIMMYT	Normal
EV DT - Y 2000 STR QPM CO.	IITA Ibadan	QPM
EV DT- W 2008 STR	IITA Ibadan	Normal
EV DT- Y 2000 STR CO.	IITA Ibadan	Normal
IAR-DENT-Q	IITA Ibadan	QPM
IAR-FLINT-Q	IITA Ibadan	QPM
KASAÏ 1	INERA Gandajika	Normal
KATOKI WA LUKASA	INERA Gandajika	Normal
LOCALE	INERA Mvuazi	Normal
MUDISHI1	INERA Gandajika	QPM
MUDISHI3	INERA Gandajika	QPM
MULTIOB EARLY DT	IITA Ibadan	QPM
MUS1	INERA Gandajika	QPM
OBA-SUPER	IITA Ibadan	QPM
SALONGO2	INERA Gandajika	QPM
SAMARU	INERA Mvuazi	QPM
ZM623	CIMMYT	QPM
ZM725	CIMMYT	QPM

CALCULATION OF STRESS INDEXES

In this study, Ri and Rs are respectively grain yields obtained during long and short rainy seasons; mRi and mRs are respectively the average grain yield of all genotypes during long and short rainy seasons. Tolerance indexes were generated on the basis of these parameters.

- The index of sensitivity to drought (SSI) was calculated using the formula of Acevedo (1991)[8]:

$$SSI = [(1-Rs/Ri)/SI] \quad (1)$$

SI being the stress intensity.

$$SI= (1-mRs/mRi) \quad (2)$$

- The stress tolerance (TOL) and productivity average have been calculated using the average [9]

TOL = Ri-Rs (3)

MP= (Ri+Rs)/2 (4)

- The performance of the stability index (SRI) was calculated according to [10]

ISR = Rs/Ri (5)

- new and improved indicators that are indicative of STI stress tolerance and the geometric average production MGP, obtained by mathematical derivations of the same yields under different circumstances [11]

STI= $[(Ri \times Rs)/(mRi)^2]$ (6)

MGP = $\sqrt{(Ri \times Rs)}$ (7)

STATISTICAL ANALYSES

The analysis of variance was made to discriminate the average yields and index sensitivity to drought. A linear regression was established between Ri and Rs yields. The principal component analysis (PCA) was done to characterize genotypes and variables, based on yield data, Rs Ri and the six indexes. The R 3.1.3 and XLSTAT software were used for data analysis.

3 RESULTS AND DISCUSSION

Analyses of variance on yields and SSI showed highly significant differences between genotypes. The varieties with SSI <1 have showed very little variation between Ri and Rs (Figure 1). Similar results were obtained by [12] which suggests that SSI values > 1 indicate a higher stress sensitivity than the average while the values of SSI <1 indicate a sensitivity to water stress below average. The variety Mudishi3 was more efficient with SSI = 0.07 compared to the local variety very sensitive to stress (SSI = 1.499). [13] showed that the performance of local variety was affected when conditions became unfavorable. This is similar to results obtained in Gandajika under PANA-ASA Project (PANA-ASA, 2013).

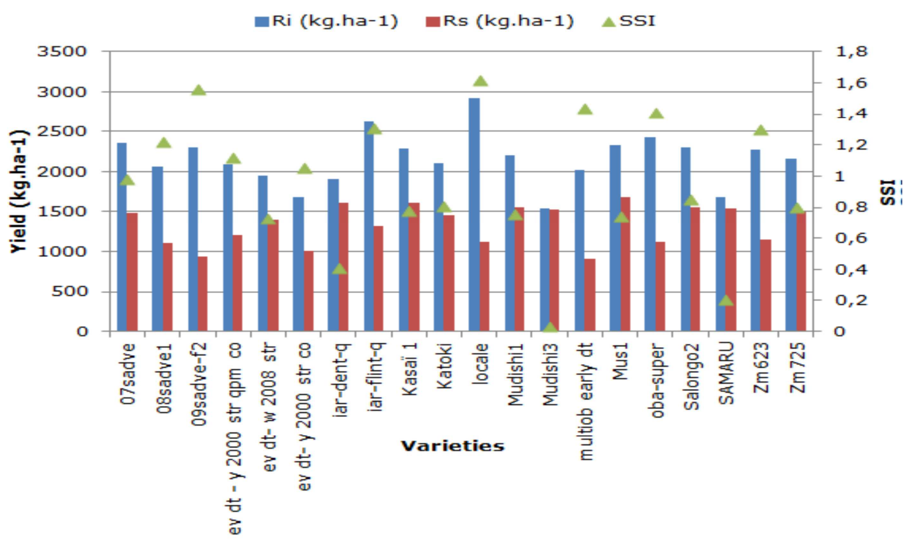

Figure 1. Average yields and index sensitivity to water stress in 2013 and 2014

Linear regression between Ri and Rs presents adverse variations. The trend line is not parallel to the x-axis with determination and director coefficients respectively r^2 = 0.017 and b = -0.171 (Figure 2), this simply means that the high yield potential under optimal conditions does not necessarily entails a high yield under stress conditions and vice-versa. In addition, productive genotypes under water stress do not necessarily perform under favorable conditions. Ref [14] attributes this response to environmental conditions for genotypes with limited or no adaptation to high humidity conditions. Genotypes with low potential production are more productive under water stress conditions.

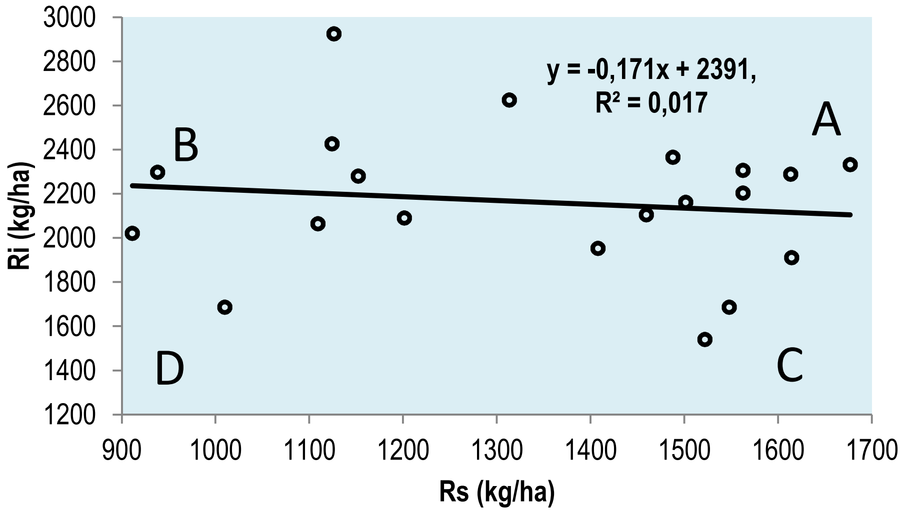

Figure 2. Relationship between Ri and Rs

These results are similar to those of [11] suggesting that genotypes can be divided into four groups (Figure2): the high-efficiency genotypes under stress and non-stress conditions (A); high yielding genotypes under non-stressed conditions (B) or stressed conditions (C) and the low-yielding genotypes under both conditions (D). High potential productivity genotypes under optimum and stressed conditions are at the extreme right on top of the trend line (Figure2), while those with high potential for production in water deficit conditions are located under the trend line at the extreme right. The least productive lines under both water regimes are at the bottom of the originally trend line abscissa.

PRINCIPAL COMPONENT ANALYSIS

Only two dimensions have an eigenvalue greater than one. These two axes provide more than 99% of the total variation. PC1 defines tolerance to water stress and discriminates the susceptible genotypes (**LOCAL, OBA-SUPER, ZM623, IAR-FLIT-Q**) with very high values of TOL and SSI with better yields during long rain while less susceptible genotypes (**EVDT-W-2000 STR, IAR-DENT-Q, KATOKI, ZM725**) have low values of these two indexes with better yields during short rain. PC2 is defining yield based on stress index, discriminate the genotypes yield based on MP, MGP, and STI. The most productive genotypes during short season (**MUS1, SALONGO2, 07SADVE, KASAÏ1, MUDISHI1**) have , MP, MGP, STI values approaching Rs. Genotypes with less SSI and TOL indexes (**SAMARU, MUDISHI3**) are high-yielding during short season and have high value of ISR index (Figure 3). When assessing the sensitivity of maize to drought, [15] showed that **07SADVE**, **MUS1, SAMARU, MUDISHI1** and **MUDISHI3** were well adapted to water deficit during the short rain.

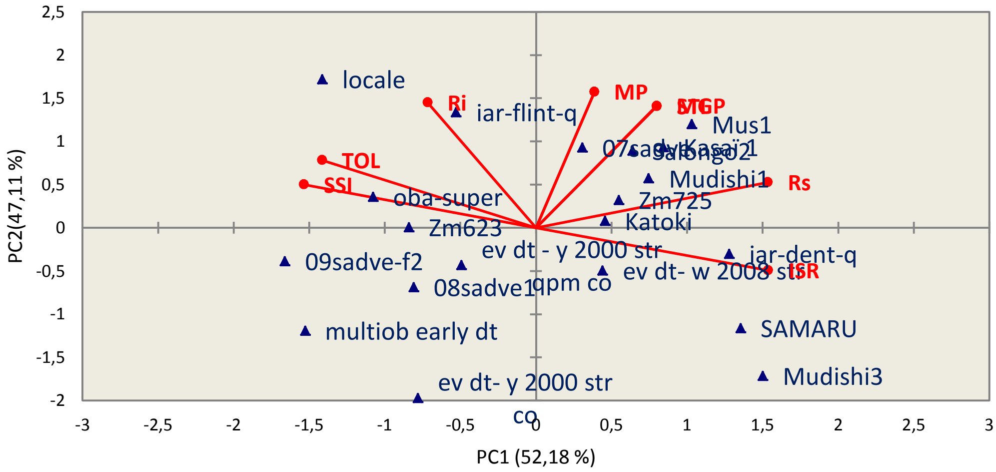

Figure 3. Genotypes distribution generated by PCA yield and stress indexes

The classification of genotypes based on yield and tolerance stress indexes showed that STI, MP and PGM deal with the same genotypes obtained by Ri, Rs. The best genotypes are those that have a high yield potential and good tolerance to water stress. However, the classification of genotypes based on the SSI and TOL are the opposite of those obtained by Ri, Rs, STI, MP and MGP. The lowest values of SSI and TOL are obtained for less sensitive to water stress genotypes, while the high values of these indexes are assigned to the most sensitive genotypes to water stress. Thus, these indexes were effective in the identification and discrimination of genotypes for their resistance to water stress. [16] found the same results and ensured that the genotypes with low SSI values are identified as resistant genotypes and all having very high SSI values are sensitive to stress. They stated that the SSI average obtained in all areas throughout the years seem to be appropriate selection index that can enable distinguish resistant from susceptible cultivars. These results are consistent with those obtained on wheat studies [12, 14, 17] the irrigated maize [18] and beans [19]. [9] demonstrated that when the more stress tolerance index (STI) and low yields in normal irrigation are close each other, the implication is that the plant is resistant to drought. In spring wheat cultivars, [12] using SSI, suggested that SSI > 1 means sensitive to stress.

4 CONCLUSION

The objective of this study was to assess the reaction of some cultivars to water stress and determine the best index to increase and improve yields under stress and non-stress conditions in DRC south western savannahs.

Results revealed that the genotypes that have high values of STI, MP and MGP and low values of the SSI and TOL are the best under both conditions. These results are consistent with the findings of several authors working on wheat, irrigated maize and bean.

Furthermore, the MGP index is often recommended for geneticists interested in relative performance, since the intensity of water stress can vary in severity in the field throughout years, while the PM is used as a resistance test to wheat cultivars under moderate stress conditions. The SSI is a very effective indicator for cereals when stress is severe, while the MP, GMP and STI are targeted when the stress is less severe. Based on their performance, **MUS1, MUDISHI1, MUDISHI3** and **07SADVE** can be used as parents in the maize breeding program for drought tolerance.

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